THE LUNAR LIBRARY™

Genesis Mission

SpaceIL Beresheet Lander

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By Nova Spivack

THE ARCH MISSION FOUNDATION

WWW.ARCHMISSION.ORG

We
dedicate the Lunar Library,
to inspire all children who look up to
the Moon, and to all dreamers who yearn for
the light. Alone, late at night, when gazing into the
milky heavens, travel out beyond the limits of time and
space. Resting simply with your mind in the presence of the
moonbeams, forget yourself, in the silence, in the radiant gap
between thoughts. It's oneness, not nothingness - transcending
nations, beyond cultures, free of gender and ageless. We are one
human family, brothers and sisters, we are the people of the light.
Believe in it, all you seers and knowers, you bringers of the dawn:
Humanity has a destiny and it whispers to us from the stars. It is
in our visions and wishes, in our hopes and in our dreams: We
sensed it in the optimism of childhood, when looking at the
sky. Treasure this calling, honor your memory, and heed
the invitation. Rejoice, all you keepers of the books,
and all you keepers of light: Like the Moon, you
illuminate the night, like the Sun, you are
starlight, like the Heart, you
shine, so bright!

by Nova Spivack
The Arch Mission™ Foundation
www.archmission.org
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Caption: The Official Front Cover of the 2019 Lunar Library - Genesis Mission, on SpaceIL Beresheet. This is a picture of the Collector's Edition version of ANALOG 1, of a 25 layer set of nickel Nanofiche™, which was presented by SpaceIL to the President of Israel. The version that is on the spacecraft is slightly different from this version in that it has the center area cut out to reduce mass and does not have names etched on the surface (the names are within the content of deeper layers of the discs). The Cover Layer is etched in at a lower magnification level than subsequent layers beneath it, in order to be naked-eye readable to anyone who finds it, and so that the content of pages can be retrieved using only 100x magnification microscope. The 4 etched circles contain ~1500 analog images of pages of text and photos at 200 dpi. It also contains logos as electro-deposited diffractives with some additional laser etching. This version of the Front Cover also includes a central mission plaque, and the names of benefactors, team members and supporters who helped to make the SpaceIL mission, and the Lunar Library, possible

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About The Arch Mission Foundation

The Memory of Humanity

The Arch Mission Foundation is a non-profit organization that maintains a backup of planet Earth, designed to continuously preserve and disseminate humanity's most important knowledge across time and space.

The Arch Mission Foundation is preserving the knowledge and biology of our planet in a solar system-wide project called **The Billion Year Archive.**

The Billion Year Archive Initiative

The Billion Year Archive will be the largest footprint and longest duration engineering project in human history. It is also the first practical initiative with potential to guarantee that our species and civilization will never be lost.

The more locations that are ARCH Libraries destinations, the greater the probability that at least some of them will survive to be discovered in the distant future.

Long after the Pyramids have turned to dust, and no matter what transpires on Earth, The Billion Year Archive will remain.

Arch Library Devices

The Billion Year Archive is comprised of ultra long-term archival storage devices called ARCH Libraries (Note: "ARCH" is an abbreviation for "archive" and is pronounced, *"Ark"*).

ARCH Libraries are the most durable records of human civilization ever built. Using new technologies, they preserve more knowledge for more time, than anything ever created.

ARCH /AR·K/

A specialized long-term archive device that is designed to hold and transmit data over very long periods of time, and in extreme environments such as in space or on the surfaces of other planetary bodies.

ARCH Libraries are being designed in a variety of form factors to persist on Earth, as well as in other locations across our solar system and beyond.

Today the ARCH Libraries are incredibly durable, yet read-only, storage devices. New ARCH Library instances must be sent out to add to the corpus.

One of the Arch Mission Foundation's goals is to catalyze and integrate new technologies that can help make the ARCH Libraries better. We are working toward a future ARCH Library platform that can be remotely updated, accessed and connected.

From Dream to Team

The Arch Mission Foundation started with an early childhood dream of co-founder, Nova Spivack, many decades ago. It was subsequently inspired by the Isaac Asimov Foundation Series, and was first written about publicly in a blog post in 2015.

Nick Slavin joined Nova Spivack to co-found the organization, and by 2016 the Arch Mission Foundation was incorporated. Soon after, the team was joined by Michael Paul, Matthew Hoerl, Josh Jones-Dilworth, and Robert Jacobson.

In 2018, the first ARCH Library was installed in the glove compartment of Elon Musk's cherry red Tesla Roadster (now orbiting the Sun for approximately 30 million years).

Subsequently, Bruce Ha, Peter Kazansky, Stephen Wolfram, Martin Kunze, Brewster Kahle, Laura Welcher, Armin Ellis, and dozens of other partners and advisors, joined the mission.

Today the Arch Mission Foundation has a growing pipeline of missions and initiatives, supported by a vibrant community of leading minds, organizations, and contributors.

Toward a Knowledge Civilization

Human civilization needs a grand unifying purpose that everyone can benefit from and help to achieve.

The Arch Mission Foundation has the potential to benefit countless beings in the future, as well as today, by uniting humanity around a shared goal of becoming a *knowledge civilization*.

As humanity shifts its focus from basic survival to the advancement of knowledge, we will become more collectively intelligent and increase our chances for long-term sustainability, development, and evolution.

Gift to the Future

The Billion Year Archive is humanity's gift to the future, and like the *Encyclopedia Galactica,* it will never be completed. There will always be more to learn, chronicle, and share as our civilization extends its footprints and handprints to the stars.

We invite and need your support and contributions. Join us to preserve, connect, and share the memories and heritage of our species.

Our Partners

The Lunar Library took three years of work to reach its first lunar landing mission, Genesis, which is scheduled to land on the Moon in April of 2019 on the SpaceIL "Beresheet" lunar lander.

Most importantly, we wish to thank our main benefactors for the Lunar Library Genesis Mission:

- **Tzili Charney and The Leon Charney Resolution Center**
- **The Sanso Trust**

The Genesis mission of the Lunar Library is made possible with the help of several partner organizations, including:

The Arch Mission Foundation Team

Mission Control

Founders

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Nick Slavin, Director

Crew

Bruce Ha, Chief Scientist
Matthew Hoerl, Production Director
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Introduction

Summary

The Lunar Library is a project of The Arch Mission Foundation (www.archmission.org), a USA-based not-for-profit organization that is backing up planet Earth.

The Lunar Library is being built across a series of missions to deliver extremely long-duration time capsules containing a curated collection of public and private libraries and other archives to the Moon.

It is being developed, and will continually be added to, by piggybacking additional installments in the library to different destinations around the surface of the Moon, with the help of lunar landings by a variety of commercial entities, non-profit organizations and governments.

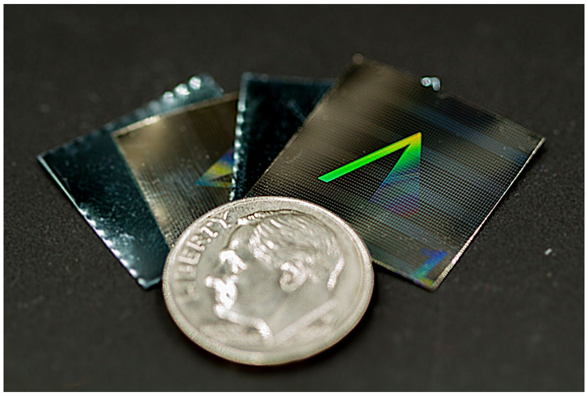
The Lunar Library is an instance of The Billion Year Archive initiative which aims to build a solar-system wide library system that can preserve, connect and share humanity's knowledge for eternity.

Nomenclature

- **The Billion Year Archive** -- A solar system-wide system of billion-year durability time capsules, containing libraries and other archives in a form of perpetual cold storage called Nanofiche. Updates are sent to locations around the solar system (including Earth) on an ongoing basis.
- **Archive** -- An accumulation of historical records, or the places in which they are located. [1]
- **Library --** A collection of information resources and/or samples or clones of DNA or cellular material, in a physical or virtual location, designed such that the resources can be shared or borrowed, but not sold.
- **Library Instance** -- A physical storage device, at a location, in The Billion Year Archive, such as an Arch Disc, that contains an Arch Library.
- **Arch Library** ("Arch" pronounced "Ark" like "archive") -- A library inside of an Instance of the Billion Year Archive.
- **Nanofiche** -- A form of ultra-long durability storage media, for preserving Arch Libraries, manufactured by NanoArchival; one of many types of storage media in The Billion Year Archive.

About the Nanofiche Archival Technology

[1] "Glossary of Library and Internet Terms". University of South Dakota Library. Archived from the original on 2009-03-10. Retrieved 30 April 2007.



Data Centric organizations such as libraries, banks, government agencies, and large corporations need to back up their most important records so that they can be retrieved in the case of catastrophic disasters. Storing data as analog images is still the only reliable way to archive information such that it can be retrieved even without access to computers and/or after required software and data specifications are no longer available.

However, the only existing analog archival systems capable of doing this are based on microfiche, a fragile film-based medium, invented in 1961. Microfiche must be maintained in a temperature and humidity controlled environment and requires clunky readers that almost nobody has or makes anymore.

Microfiche has a life expectancy of up to 800 years, under ideal HVAC-controlled conditions. However most State Archives only certify microfiche for 25 to 50 years, after which a new copy of the media must be generated.and has a shelf life of only 50 years before it must be rewritten. Microfiche also is unsuitable for use in space, or any high-heat or high-radiation environments, such as the Moon.

The content of the Lunar Library is encoded in a breakthrough new archival data storage technology called Nanofiche. Nanofiche is a patented, proprietary technology of NanoArchival, a partner and supplier of the Arch Mission Foundation. Nanofiche encodes information as analog or digital etchings in thin films of nickel at 300,000 dots per inch using optical nanolithography.

Nanofiche is orders of magnitude more durable than microfiche and costs orders of magnitude less to store and maintain. The Arch Mission Foundation chose Nanofiche for the Lunar Library because it is ideally suited to preserving information in the harsh environment of space and the surface of the Moon.

A detailed summary of the benefits of Nanofiche, and how it is manufactured, is provided in Appendix 1.

Other New Technologies We are Researching

Nanofiche is currently the only solution to the data storage and preservation needs of the Billion Year Library that can meet our needs today and for the next 10 years, at least. Nanofiche offers the benefits of low-cost, long-durability, ease-of-use, and in particular, support for both analog and digital data formats.

The Arch Mission Foundation is constantly exploring emerging technologies that may benefit our work today as well as on longer time-scales. Emerging technologies we are currently working with include:

5D Optical Memory is a technology, developed by Arch Mission advisor, Dr. Peter Kazansky, at the Optoelectronics Research Centre at the University of Southampton.

The Arch Mission Foundation delivered the first Arch Library using this technology, when it placed the Isaac Asimov Foundation Trilogy into 30 million-year solar orbit in the glove compartment of Elon Musk's Tesla, in February of 2018.

A 6 inch diameter disc of quartz has a theoretical 5D storage capacity of 360TB and the data is stable under a wide range of conditions, for at least 14B years.

However the challenges today are write-speed and read-out. Write-speed is still quite slow and it will be 10 years until it is comparable to existing forms of optical storage in use commercially today.

There is also no automated way to verify or read-out the data; until one is invented, read-out has to be done bit-by-bit with a microscope, which is not practical for large volumes of digital data. Systems to automate read-out are being worked on but are at least 10 years from being available outside of research.

One further possible limitation is that 5D is only applicable for digital storage - not analog data storage. Digital storage is inherently riskier than analog storage because it requires the use of a computer, the right software and knowledge of the data format.

Molecular Data Storage in DNA includes two approaches to using the molecular structure of DNA to store and recover digital data: storing data in synthetic DNA, and storing data in naturally occuring living DNA.

Storing data in synthetic DNA is being researched by multiple Arch Mission Foundation advisors and partners at organizations including, Microsoft Research, Catalog, University of Washington, and Carverr.

Molecular storage in DNA is presently of interest to DARPA, and other organizations that are anticipating the coming costs of backing up and transmitting datasets in the Exabyte-scale world we are entering. DNA molecules offer large storage capacity in small volumes of material, and low cost storage and replication, making them ideal for cold storage of big data sets.

Storing data in naturally occuring living DNA is being researched by synthetic biologists at universities around the world, and we have been studying this and participating in research. This approach explores whether there are regions in the genomes of living organisms, such as bacteria or humans, that are suitable for storing and transmitting data over many generations.

Storage in living DNA is achieved using gene-editing techniques such as CRISPR and retrieval is achieved using existing DNA sequencing and replication technologies. The challenge is that is unclear if there are any unused regions of living genomes that are also maintained and passed down over time. Non-coding regions of the genome, such as the “junk DNA” region, are not error-corrected during reproduction. It appears that only the coding regions that are tied to genes with selective advantages are preserved over time.

DNA is highly stable for millions of years under the right conditions, however it must be protected from high heat and radiation and not well-suited to preserving data in outer space or on other planets that do not have magnetospheres.

Today these technologies are still in the early stages, however a few of our partners are nearing first commercialization of their technologies, for specific narrow use-cases.

It will be at least 10 years before the technologies exist for wider applications. One of the challenges is that systems for rapidly writing and reading from computer systems to DNA storage are still only starting to be designed; write-speeds and read-out speeds are far from being competitive with commercially available forms of non-DNA storage.

In addition to the above research into data storage, we have two initiatives for preserving physical artifacts (such as for long durations:

The Artificial Amber initiative explores the use of synthetic resin to preserve the tissues and DNA of biological organisms for long durations, much like the tree resins that have preserved intact insects and plant tissue samples for hundreds of millions of years on Earth. The use of slow-cure epoxies by entomologists is an example of this approach. Viable DNA is recoverable from samples preserved in amber, even after long time-scales. We are interested in whether it is possible to improve on this with artificial resins that can further protect biological samples against radiation damage and heat.

The Civilization Box initiative seeks to invent technologies to preserve not only data, but the tools for accessing the data, for millions of years or longer. This is challenging because all our present-day computer technologies make use of carbon-based materials, such as plastics, which decay over time. They also make use of metals and other materials that oxidize. The question this initiative addresses is whether there is a way to preserve such devices so that they

decay more slowly, and can be restarted in a million years. This requires that we not only preserve computers, but also any data storage and retrieval devices, the data input and output devices, and any necessary cables and power supplies. One approach is to store these items in argon gas, inside of specially shielded containers that are then stored underground, undersea or in outer space.

Mission History and Roadmap

The Arch Mission Foundation is designed to continue on an ongoing basis. We name our missions by the nearest planetary body, and then the storage location and and any relevant mission name or brand for the delivery partner.

Our scheduled missions include:

- The Solar Library: Tesla Solar Orbiter, (2018). We placed the Isaac Asimov Foundation Trilogy, within a 5D quartz crystal disc, into 30 million year solar orbit, in the glove compartment of Elon Musk's Tesla.
- LEO Library - Constellation 1, (2018). With SpaceChain, we deployed a digital copy of the English Wikipedia onto a cubesat in low-earth orbit, in solid state storage.
- Lunar Library - Genesis, (2019). With SpaceIL, we are delivering the first large Arch Library, on a 25-layer nickel Nanofiche disc, to Mare Serenitatis on the Moon.

Upcoming Missions in early-development with partners include:

- Earth Library - Eden
- Lunar Library - Peregrine
- Lunar Library - Apollo
- Lunar Library - Malapert
- Leo Library - Constellation 2
- The Lagrange Libraries
- The Mars Libraries

The History of Archiving

An archive is “an accumulation of historical records, or the places in which they are located.”[2]

One of the best resources for charting the history of archiving can be found in Jeremy Norman’s History of Information Web site.

There is an important distinction to be made between two types of archival projects, those that are primarily designed to be accessed by a contemporary audience of the curators, and those that are designed for an audience in the future.

The former are usually referred to as libraries, while the latter are referred to as backups or time capsules; however, some libraries are also designed to last and function as time capsules as well.

A library is a special type of archive, designed with the intention making its content available to some audience through sharing or lending, but not commercial transactions.[3]

Time capsules and backups, on the other hand, may contain copies of libraries, but are themselves not intended to be accessible as actual libraries until some point in the future when they are recovered.

Wikipedia provides a good overview of the History of Libraries. The full text of Ernst Posner’s classic, Archives in the Ancient World is available here. The Khan Academy provides an accessible summary of Recordkeeping and History.

For a comprehensive general overview of time capsules on Earth, see Wikipedia page on time capsules, Wikipedia List of time capsules, and Timeline of time capsules. Oglethorpe University also provides a good resource on the subject, including a history of their very own Crypt of Civilization, and the International time capsule Society Registry of time capsules.

Time capsules are typically placed on Earth and are usually (but not always) designed to be opened within the lifespans of their creators, or their descendants within a few generations.

However, there are also a small number of time capsules in space, including The Arch Mission Foundation’s, Isaac Asimov Foundation Disc. This disc was sent into 30 million year Solar orbit in 2018, in the glove compartment of Elon Musk’s Tesla, which flew on the SpaceX Falcon Heavy Test Launch.

[2] "Glossary of Library and Internet Terms". University of South Dakota Library. Archived from the original on 2009-03-10. Retrieved 30 April 2007.
[3] https://en.wikipedia.org/wiki/Library

The Arch Mission Foundation's Billion Year Archive initiative is a hybrid of a library and a time capsule: It is a time capsule that is designed to become a library, in the future. In other words, it is a set of datasets designed to be replicated and updated continuously, within and across a spatially and temporally distributed series of time capsules, so that in the future it can be used as a library.

Major Initiatives We Learned From

It is important to acknowledge that the Arch Mission's ambitions to back nup planet Earth did not arise in a vacuum. Many other thinkers, projects, and organizations have been working on similar and earlier projects for decades or even longer. Their work informed and inspired our work and its worthwhile to review several of the more relevant examples.

In addition, there have been several notable missions to deposit time capsules in space before the Arch Mission came into existence. The Pioneer Plaques are perhaps the best-known example. They are a pair of gold-anodized aluminum plates that flew on Pioneer 10 and 11 in the 1970's.

The plaques were designed by a team including Eric Burgess, Carl Sagan, Frank Drake, and Linda Salzman Sagan, with the purpose of communicating a basic understanding of our species and its location in the universe to extraterrestrials.

The Pioneer Plaques generated controversy for attempting to accurately depict nude human figures, leading to an editorial decision to remove the details of the female sexual organ, while leaving the male sexual organ intact in the final version that went to space.

As well as potentially misinforming aliens into concluding that humans reproduce asexually, the plaques raised a number of concerns among some critics because they depicted mainly caucasian racial characteristics. Despite an attempt to universalize the drawings so that they represented features common across humanity, many critics were unhappy with the results.

Arch Mission advisor William Alba, director of the Science and Humanities Scholars Program at Carnegie Mellon University, has surveyed several other recent attempts at archiving civilization on Earth and in space for the Lunar Library initiative.[4] He summarizes:

> "**The Westinghouse Time Capsule** of the 1939-1940 New York World's Fair is the object first called a "time capsule." While it is not the earliest artifact targeted to be opened on a specified date (in this case, the year 6939), it inspired many similar projects. The contents of the capsule reflect an optimism that material ingenuity will lift the United States from an economic Great Depression. Because those objects cannot be duplicated here, this archive of civilization is

[4] Excerpted from A Brief History of Archiving Civilization, William Alba, 2018; a special collection the Arch Mission Private Collections in the SpaceIL Lunar Library.

represented here by The Story of the Time Capsule and The Book of Record of the Time Capsule of Cupaloy.

Voyager Golden Record, created four decades after the Westinghouse Time Capsule, was inspired in part by Carl Sagan's childhood visit to the Westinghouse Time Capsule. It is the culmination of a series of Space Age projects ostensibly designed to communicating with extraterrestrials or humans of the distant future, which includes Freudenthal's Lincos project, the Arecibo radio broadcast, and plaques and discs on the LAGEOS satellite, Apollo landers, and Pioneer 10 and 11 spacecraft. The Voyager Record is represented here by a photograph of its exterior, as well as the images and sounds encoded on the long-playing record.

Earth Tapestry, created four decades after the Voyager Golden Record, uses crowdsourcing to curate the locations on Earth that are most significant to voters. Starting with 240 locations, this project enables Internet users to decide collectively which places are the most awe-inspiring, delightful, durable, famous, information-rich, ingenious, irreplaceable, and noble. The project arises from the technological possibility and social obligation to seek a greater diversity of perspectives as we begin to practice messaging with extraterrestrial intelligence. It was developed at Carnegie Mellon University in conjunction with the MIT Media Lab, and is represented here by a sample voting page, current ranks for each location, and a map of the ten locations that rank most highly across all eight criteria."

Another important initiative is Memory of Mankind, which is a close partner with the Arch MIssion. Martin Kunze deserves a lot of credit for paving the way for the field of archiving humanity.

Memory of Mankind (MOM) is a preservation project funded in 2012 by Martin Kunze. The main goal is to preserve the knowledge about our present civilization from oblivion and collective amnesia. Information is printed on ceramic tablets, then stored in the salt mine of Hallstatt, Austria. More than a simple archive project, it aims to create the "Time capsule of our era", letting people participate by allowing them to submit texts and images. In contrast to national archives, content for MOM is collected by anyone who takes part. It is a collective, "bottom-up" told history.[5]

There are also a number of important digital archiving and preservation projects, focused on collecting and sharing open-access knowledge that have informed our work:

The Internet Archive is a San Francisco–based nonprofit digital library with the stated mission of "universal access to all knowledge." It provides free public access to collections of digitized materials, including websites, software applications/games, music, movies/videos, moving images, and nearly three million public-domain books. As of October 2016, its collection

[5] https://en.wikipedia.org/wiki/Memory_of_Mankind

topped 15 petabytes. In addition to its archiving function, the Archive is an activist organization, advocating for a free and open Internet.

The Rosetta Project is a project of the Long Now Foundation which aims to collect information on the world's nearly 7,000 languages and create the Rosetta Disk which is an analog backup of the collection that can last for thousands of years. As many of the world's languages are endangered the project also stands as a testament to the world's linguistic diversity at the dawn of the 21st century, a picture which may greatly change in coming centuries. The first Rosetta Disk was completed in 02008. In 02016 a wearable version of the archive was created. This wearable version had 1,000 microscopic pages formed into a disk of nickel and contained the Preamble to the Universal Declaration of Human Rights as its main parallel text, and vocabulary from the PanLex collection as its main parallel wordlists.

The **PanLex** Project is a project of the Long Now Foundation that is building the world's largest lexical translation database. By transforming thousands of translation dictionaries into a single common structure, the PanLex database makes it possible to derive billions of lexical translations that are not found in any single dictionary. PanLex data is included in the Rosetta Wearable Disk in analog form. The PanLex dataset was also contributed to the Lunar Library and is included in its entirety in digital form.

Wikipedia is a multilingual, web-based, free encyclopedia based on a model of openly editable and viewable content, a wiki. It is the largest and most popular general reference work on the World Wide Web, and is one of the most popular websites by Alexa rank.[6] It is owned and supported by the Wikimedia Foundation, a non-profit organization that operates on money it receives from donors.

Project Gutenberg is a volunteer effort to digitize and archive cultural works, to "encourage the creation and distribution of eBooks". It was founded in 1971 by American writer Michael S. Hart and is the oldest digital library. Most of the items in its collection are the full texts of public domain books. The project tries to make these as free as possible, in long-lasting, open formats that can be used on almost any computer. As of 23 June 2018, Project Gutenberg reached 57,000 items in its collection of free eBooks.

In addition to these recent examples, there are major and important projects to archive Earth's biology, such as the Svalbard Global Seed Vault and Genbank. In the area of preserving humanities art and technologies there are many natural history museums, art museums, specialized museums of invention and technology, historical museums, and national archives that have assembled impressive collections of knowledge and artifacts.

The Arch Mission Foundation's work builds on the thinking of these projects, as well as other initiatives from IT and fields outside the usual scope of archival preservation. We are not the first ones to think of many of our ideas, but we may be the first to combine them.

Our Curation Approach

The issues that emerged from the Pioneer Plaque controversy illustrate the inevitable pitfalls of any attempt to distill the characteristics of all of humanity into a small set of generic examples, and are one of the major reasons why the Arch Mission Foundation chose instead to err on the side of over-sharing, by sending as close to “everything” as we can fit on our missions.

Instead of trying to create a generic representation of humanity, our approach is to represent the full diversity of human civilization, cultures, ethnicities and perspectives with as much variety and quantity as possible.

We “curate the curators” by collecting and sending vast collections of human knowledge and art, created by others more knowledgeable than us, rather than exercising fine-grained editorial control over each subject area and piece of content, or attempting to develop “perfect” original content ourselves.

We are mindful that we need to be inclusive yet balanced at the same time. Our goal is to be accurately proportionally reflective of the relative distributions of beliefs and perspectives in the world today, and in the past.

Our approach to accomplishing this is to backup large crowd-sourced data sets like Wikipedia, Project Gutenberg, and selections from Archive.org -- rather than attempting to build our own voting and ranking mechanisms for content.

At the same time we do provide for the inclusion of private archives, curated by others with particular biases and perspectives, where we are convinced that the potential value of such archives to people in the future is great enough to warrant including them. In this area we exercise curational discretion in deciding what to transmit.

The “big data” approach that we are taking would not have been possible in the 1970’s when the Pioneer Plaque was designed. The reason it was a plaque, not a giant database, was due to technological constraints of the time, not a lack of vision on the part of Carl Sagan and the others on that team. Had they had access to the technologies we have access to today, we believe they would have made similar choices, and had similar ambitions, as us.

The Architecture of the Lunar Library

The Physical Artifact

The Lunar Library is contained on a specially designed Arch Disc, which is actually comprised of 25 thin nickel films, created using a new technology called Nanofiche, for the Arch Mission Foundation, by NanoArchival (www.nanoarchival.com).

Nanofiche is a nanotechnology for storing data so that it can last for extremely long durations. It is made of pure nickel, which is impervious to radiation and temperatures on the Moon, and can last for billions of years without losing any data.

Each layer of Nanofiche is created using a process called optical nanolithography, in which data is first etched to glass by laser at 300,000 dots per inch, and then grown at atomic scale in nickel using an electro-depisition process. Each layer is only 40 microns (0.04mm) thick and weighs only 4 grams.

The entire 120mm diameter Arch Disc, of 25 layers of Nanofiche, weighs only 100 grams and is only 1 mm in thickness once assembled, which is about the size and weight and thickness of a DVD. Although quite small, this artifact contains approximately 30 million pages of knowledge, making it one of the most information-dense objects humanity has ever made.

The top 4 layers of the Lunar Library are encoded as analog images and comprise more than 60,000 pages at 200 dpi, viewable with 150X to 200X magnification optical microscope. This level of magnification has been available since the 1600s.

The Arch Mission Foundation chose to encode the top layers as low-magnification optical images so that potential future discoverers of the time capsule would be able to see and read content, without needing a computer.

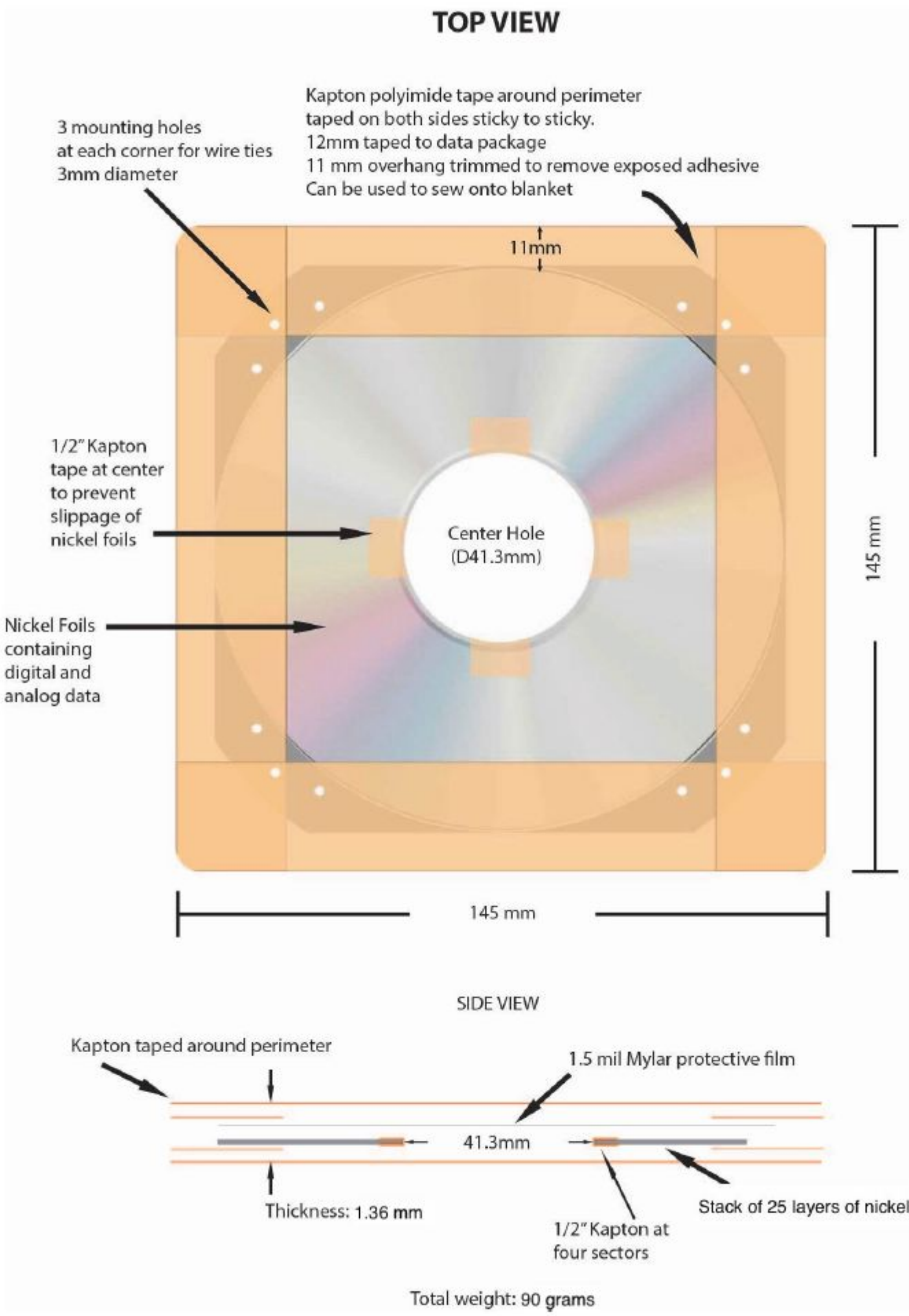
Included in the top 4 analog layers, is a special section called the Arch Mission Foundation Primer, which uses pictures and diagrams to teach what is on the discs, how to understand human languages and concepts, and how access and extract knowledge from the deeper layers.

The deeper 21 layers contain 100GB of compressed digital archives in DVD format, which decompress to almost 200GB, comprising the bulk of the 30 million pages of the Lunar Library.

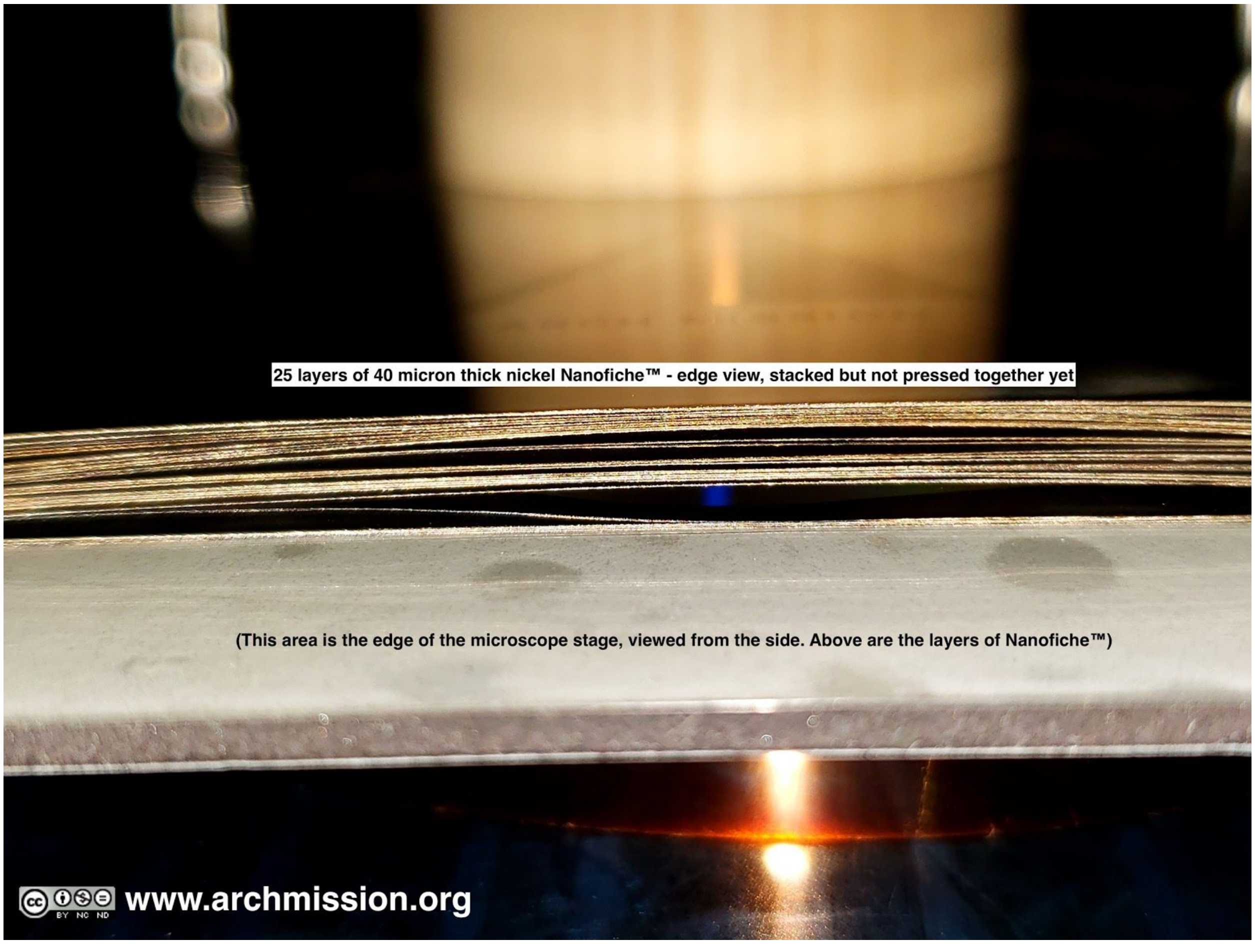
For delivery to the Moon on the SpaceIL Beresheet lander, The Lunar Library is encased in special materials to protect it during spaceflight. It is installed inside a special protective container that was made for it by SpaceIL, located inside the Beresheet lander, where it will be protected from the Lunar environment, and is estimated to last from 50 million to several

billions years (depending on whether it is eventually hit by meteorites and how long the Moon lasts).

If printed out on 8.5” * 11” sheets of paper, the Lunar Library would take up more than 30 million pages. A stack of 30 million pages would be 2 miles tall, or about 4 times the height of the Burj Khalifa, the tallest building in the world.



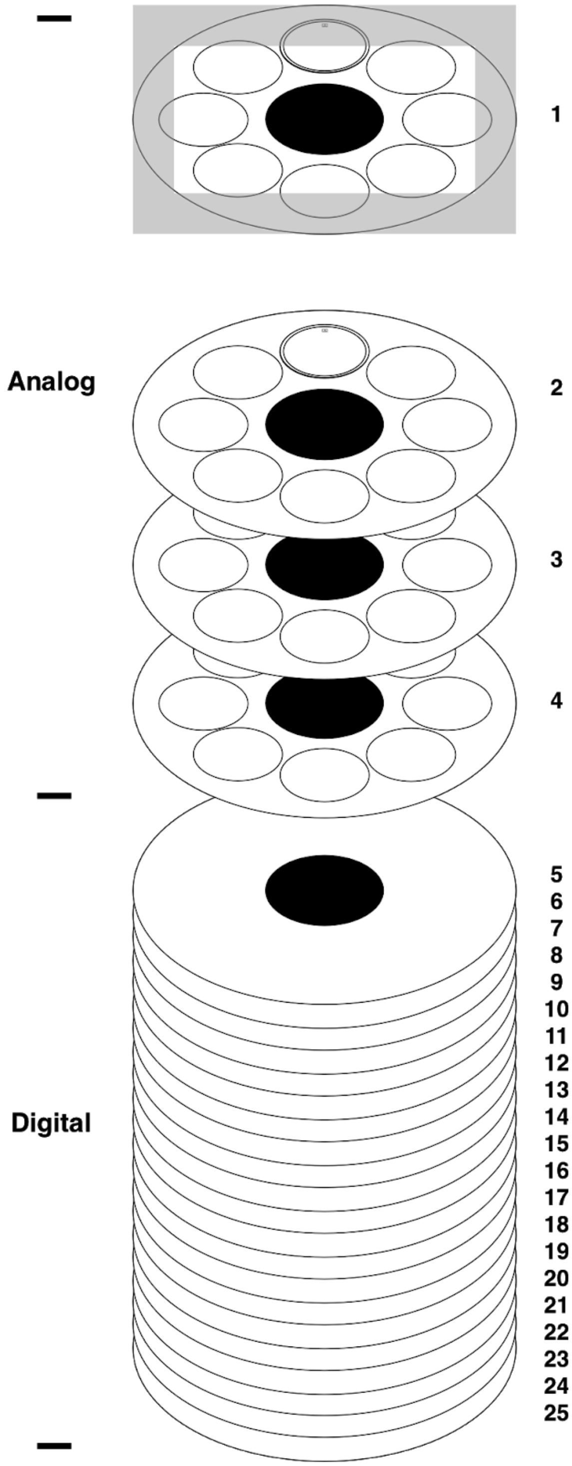
Caption: Diagram of the physical of the Lunar Library from the Technical Specification for the payload. The actual final payload weighs just under 100 grams.



Caption: Lateral view of an early test-print of the Lunar Library Disk stack, prior to the final version production. This shows 25 layers of 4 micron foils of Nanofiche, stacked up on top of a microscope stage, viewed from the side. In the final product, the layers are tightly pressed together. The back of each layer is smooth and has no data on it - the etched data is only on the top surface of each layer.

Caption: Insertion of the Lunar Library Disk stack into multi-layer insulating materia**ls.**

Caption: Ceremony at IAI by SpaceIL founders and engineering team, prior to installing the Lunar Library Disk into the spacecraft.



Caption: The Architecture of the Lunar Library from The Arch Mission Primer sections of the Lunar Library.

THE CONTENT OF THE LUNAR LIBRARY

The total size of the library in uncompressed form would be ~200GB. The Library comprises more than 30,000,000 pages of information, as well as large sets of analog data (images of pages of text, photos, etc., written in analog format, not digital format, to the disc surfaces) as well as digital multimedia resources (audio, video), software, binary datasets, and more.

The Lunar Library consists of 25 layers of nickel nanofiche. The top 4 layers are analog etchings. The next 21 layers are digital DVD masters etched in nanofiche film.

The Lunar Library contains 21 layers of digital data in DVD format, which under a sufficiently powerful microscope or scanning device (such as a laser powered read-out device) appears as a series of pits and lands. A spinning disk spindle is used to retrieve these at high speed in optical disk readers. It is also possible to read this out into static images which can then be processed in a computer memory (without spinning the surface) to extract the data.

All of the necessary technical specifications[6], scientific knowledge, mathematical knowledge, and engineering knowledge, necessary to reading-out and then decoding this type of digital data is included in the analog layers of the Lunar Library, above the digital layers.

Thus, without a microscope all necessary technical knowledge is obtainable, such that a sophisticated party can then retrieve the deeper layers of digital data. In addition, all the necessary knowledge to further decoding and interpreting any datasets that are retrieved from the digital layers are also taught in the Primer and also in more detail in the digital layers. Included are all the specifications of the relevant file formats, standards, and the actual source code and compiled code of the necessary software and algorithms.

In addition detailed knowledge, in the form of thousands of books on computers, electronics, semiconductors, computer science, advanced optics, lasers, encryptions and data compression, operating systems and the like are included. The necessary specifications are only encoded in formats that are taught in the analog layers.

The result is a "staircase of knowledge" where the higher analog layers are designed to teach lower-technology recipients what they need to know to access the deeper digital layers, which then continue to teach how to access and decode all encodings in the even deeper layers of file formats and archived information within the digital layers.

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[6] An example of a technical specification that is written into the analog Primer includes: ECMA-267 which defines the DVD standard and how to read data encoded into the surface of a DVD. All the necessary linguistics and concepts, as well as technical and scientific principles are taught in the Primer and other sections of the Lunar Library in analog format. https://www.ecma-international.org/publications/files/ECMA-ST/ECMA-267.pdf

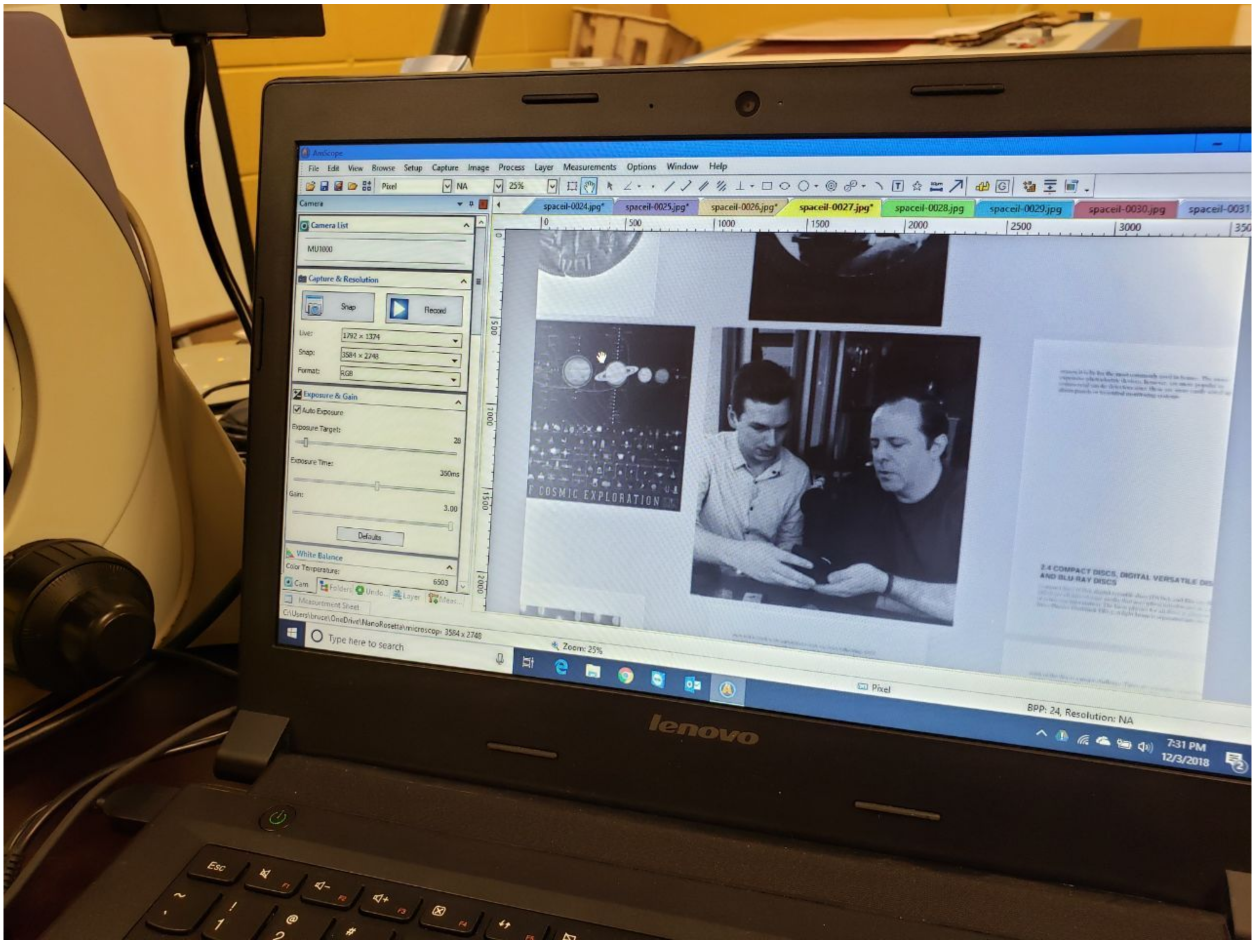
SUBJECTS IN THE LUNAR LIBRARY

- Aerospace
- Agriculture
- Almanacs and Directories
- Animal Care and Breeding
- Anthropology
- Archeology
- Architecture
- Biographies
- Business
- Cartography
- Classics
- Commerce and Industry
- Communication and Media
- Computer Science
- Construction
- Creative Writing
- Criminology
- Cultures, Ethnicities and Civilizations
- Death and Dying
- Dentistry
- Design
- Dictionaries and Encyclopedias
- Diplomacy
- Earth Sciences
- Ecology
- Economics
- Education and Teaching
- Engineering
- Entertainment
- Environmental Science
- Fashion
- Fiction
- Film, Television and Radio
- Finance
- Fine Art
- Fishing
- Folklore and Mythology
- Food and Drink
- Forestry
- Genealogy
- General Knowledge
- Genetics
- Geography and Atlases
- Geriatrics
- Government
- Handicrafts
- Health
- Heraldry
- History
- Hobbies
- How-To and Training
- Humanities Studies
- Humor
- Native and Indigenous Studies
- Interior Decorating
- Languages and Language Learning
- Law
- Lettering and Printing
- Library Science
- Logic
- Management
- Mathematics
- Medicine
- Military Science
- Museums and Collecting
- Music
- Naval Science
- News
- Nursing
- Oceanography
- Parenting
- Performing Arts
- Philosophy
- Photography
- Poetry
- Political Science
- Pop Culture
- Psychology and Mental Health
- Public Policy
- Recreation
- Relationships
- Religion and Spirituality
- Survival
- Science
- Self-Help
- Sexuality
- Social Work
- Society
- Sociology
- Software
- Space
- Sports
- Statistics
- Survival
- Technology
- Textbooks
- Transportation
- Travel
- Unexplained
- World Heritage
- Women's Studies

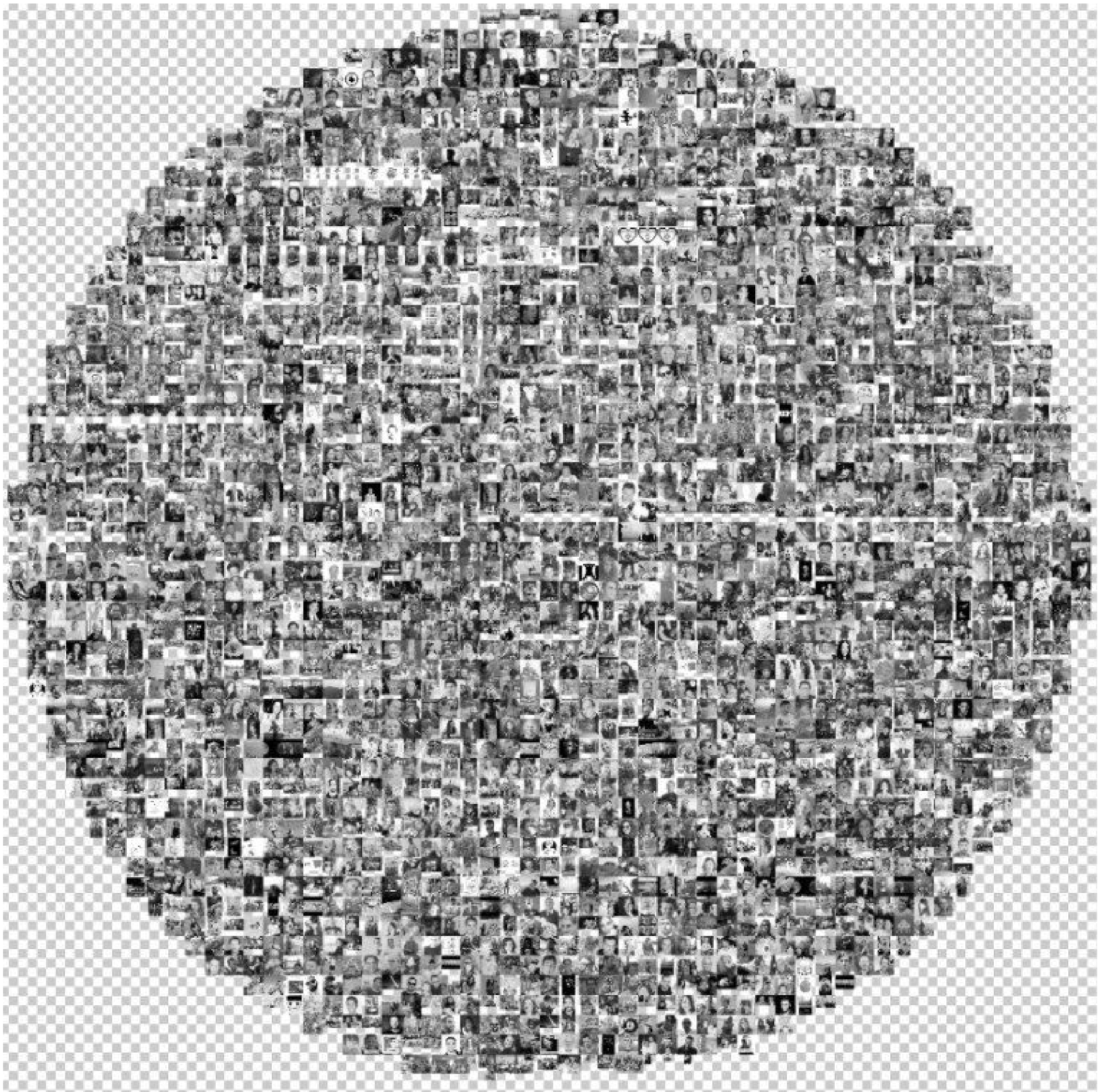
THE ANALOG LAYERS

ABOUT THE ANALOG LAYERS

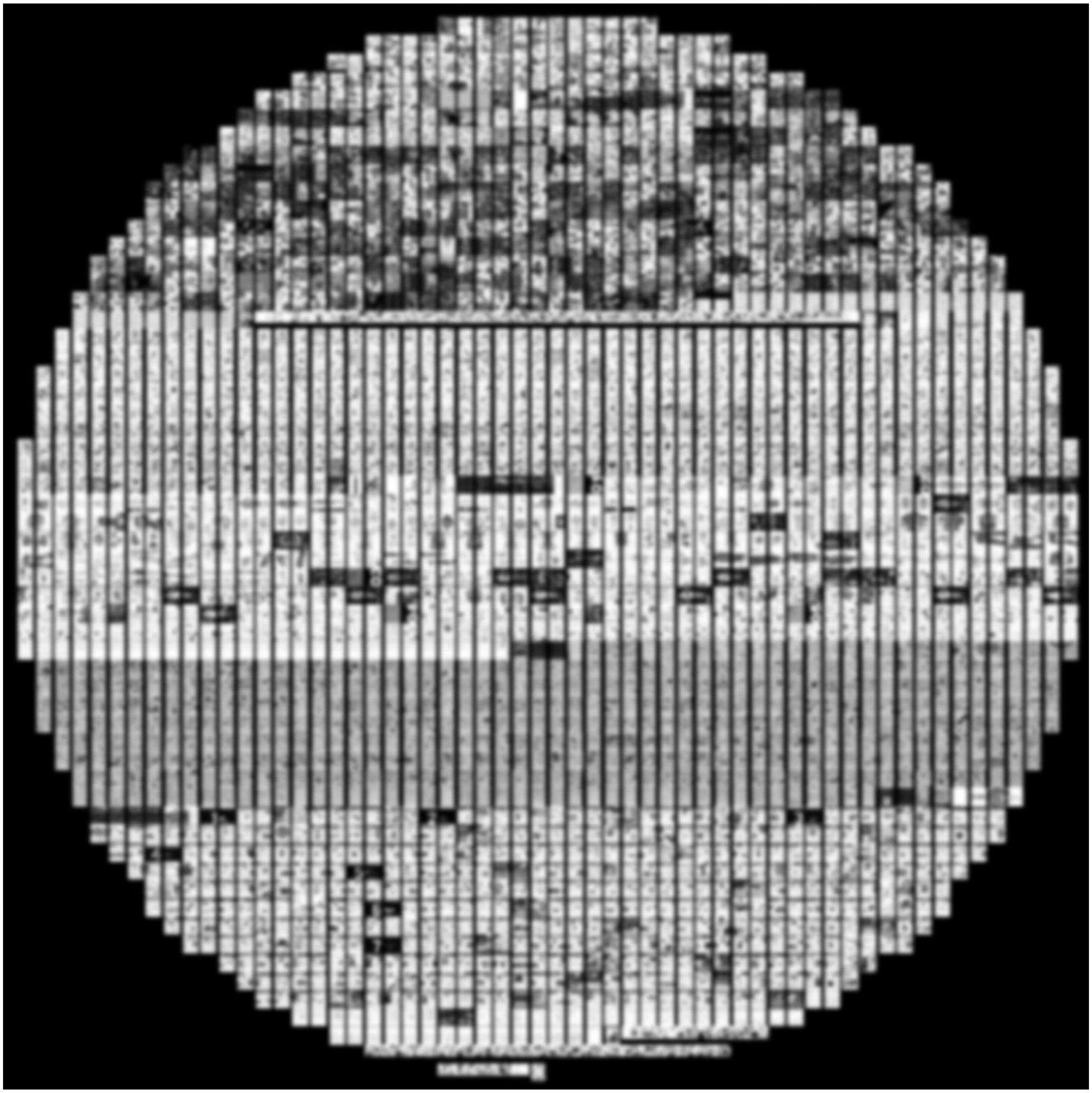
- 4 Discs of Analog Nickel Nanofiche
- Each 120mm disc is only 40 microns (0.04mm) thick
- The Analog Layers contain more than 60K images of pages of text, photos, illustrations, books, etc.
- Each of the 8 circles etched into each analog layer contains 14.4 billion pixels, therefore each analog layer has an etched surface area comprising 115.2 billion pixels.
- The reason we store information as analog images on the top layers is that in the future they can be accessed with a very simple magnifying glass or microscope; no computers required. This makes it particularly easy for future recipients to retrieve this content.
- The first layers of the Analog section include a Primer consisting of thousand of pages that teach the meanings of more than 1 million words and concepts, using pictures and diagrams labelled and explained with text in many languages. In addition the Primer includes a large trove of technical and scientific specifications that teach how to retrieve and interpret the digital data encoded on the deeper digital layers of the library.
- In addition to the Primer the analog layers contain many additional collections of knowledge about a broad range of subject matter.



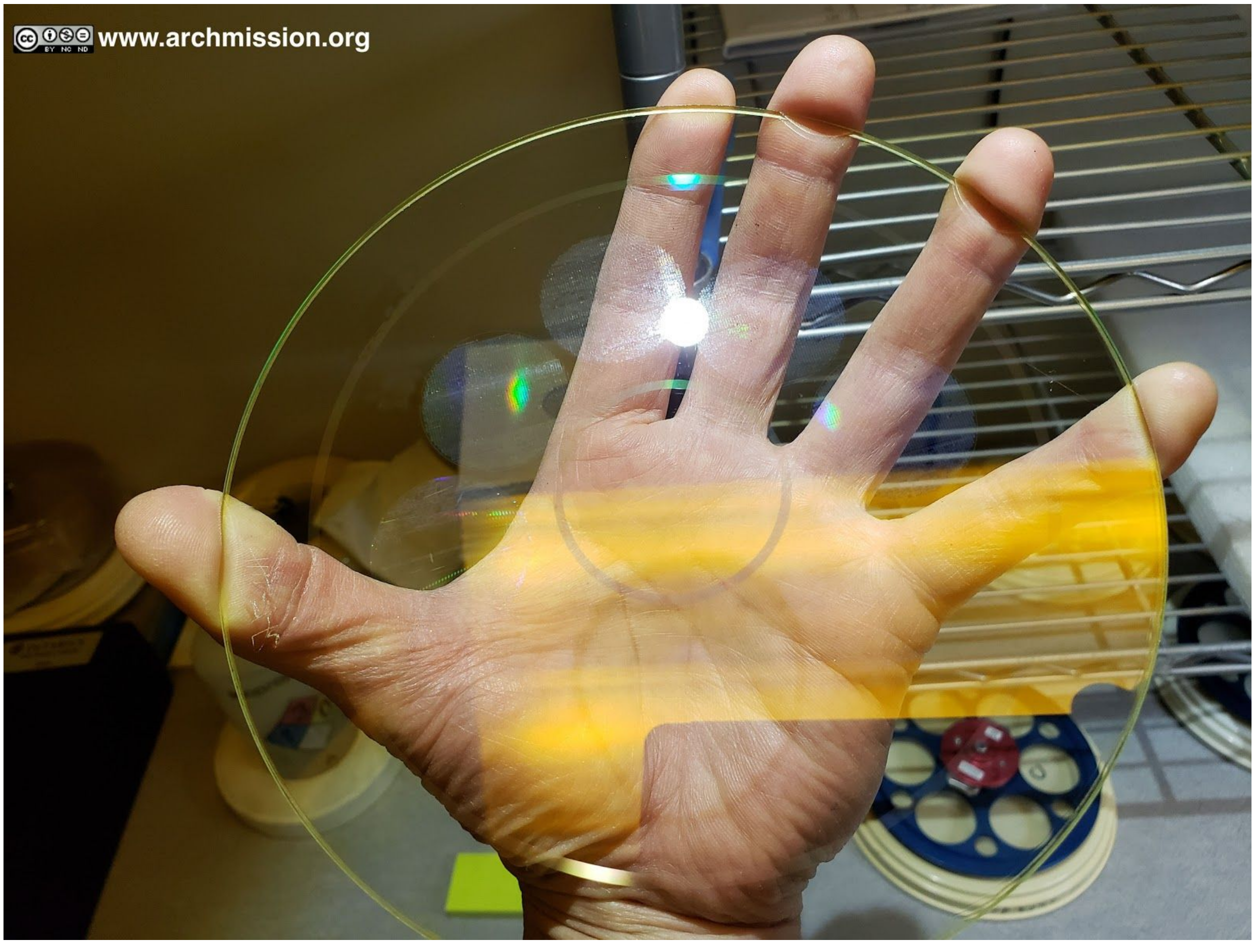
Caption: View of a composite of an analog section of the Lunar Library



Caption: A 14.4 billion pixel rendering of one of 8 circles in an analog layer of the Lunar Library containing photos of people who helped with the SpaceIL mission to the Moon.. The images are written at 200 dpi. All 8 circles per analog layer contain the same number of pixels per circle, therefore the entire etched area surface of each layer is 115.2 billion pixels.

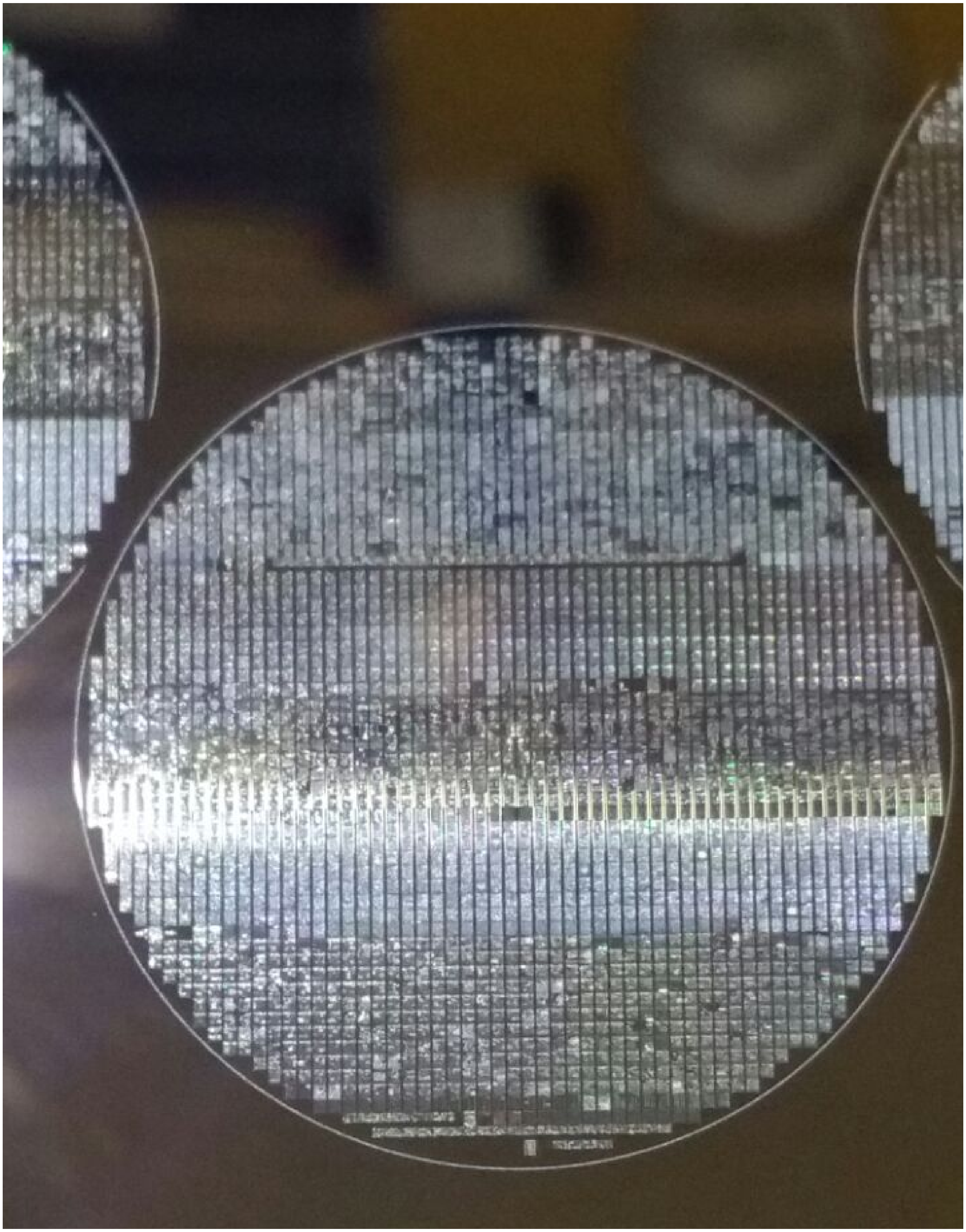


Caption: Layout for one of the circles of analog data in the Lunar Library Primer section, digitally blurred in post-processing of this image to protect Copyrights of certain contributed content. The data is not blurred on the actual discs. This image shows approximately 2000 pages etched into nickel Nanofiche on one of the Lunar Library Disks. In 50 years, once present-day Copyrights expire we can reveal all the content in detail. There are nearly 60,000 pages in analog format across the 4 analog layers.

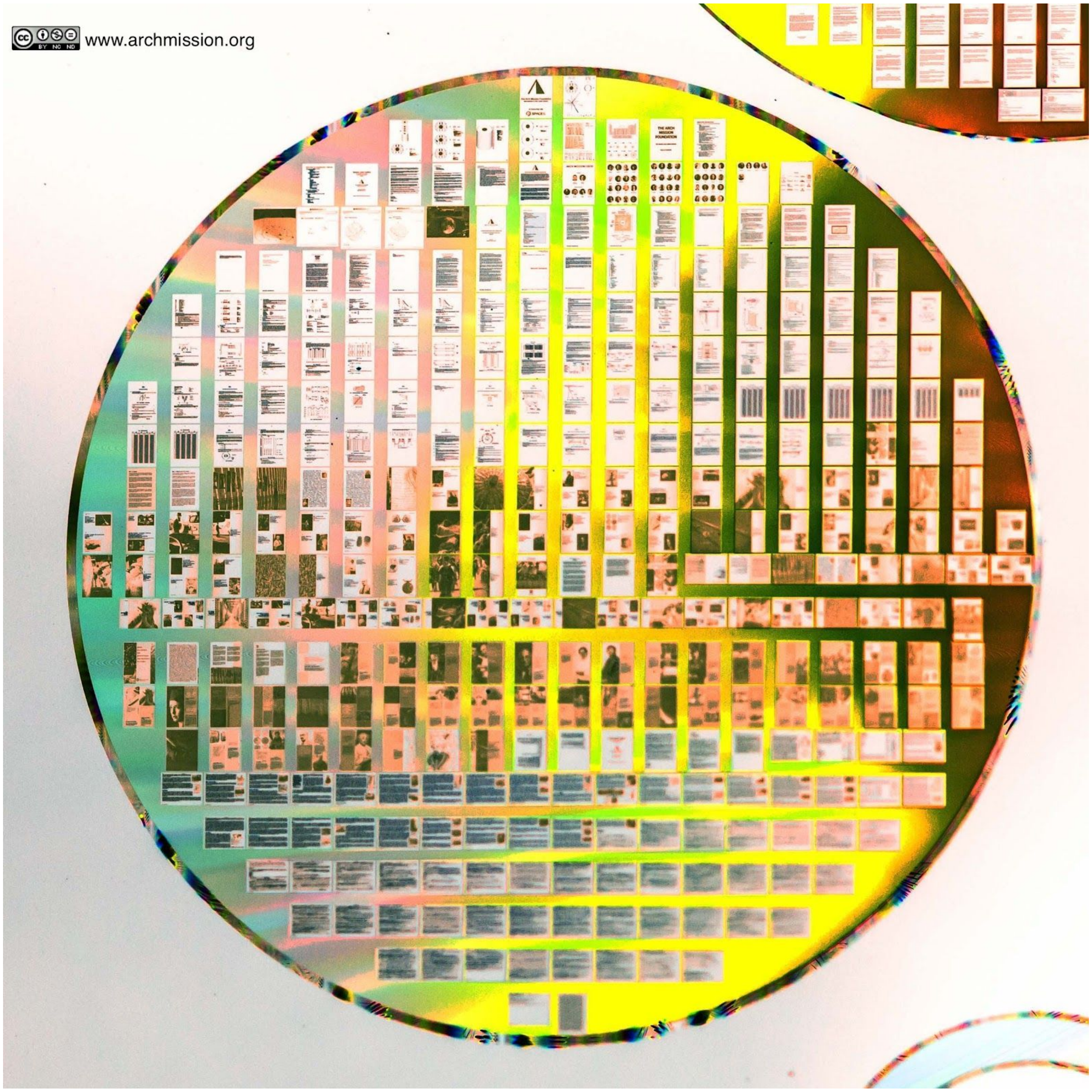


Caption: One of the glass masters produced at the start of the Nanofiche production process. The glass master is written at high speed using a patented polar-raster method, by NanoArchival at Stamper Technology. The content is etched by laser into the glass at 300,000 dpi (dots-per-inch). From this glass master, a thin nickel foil is grown by electro-depositing the nickel atom-by-atom at the atomic scale. The resulting foil is then separated from the glass and further generations of nickel are then grown from that to produce the final Nanofiche disc.

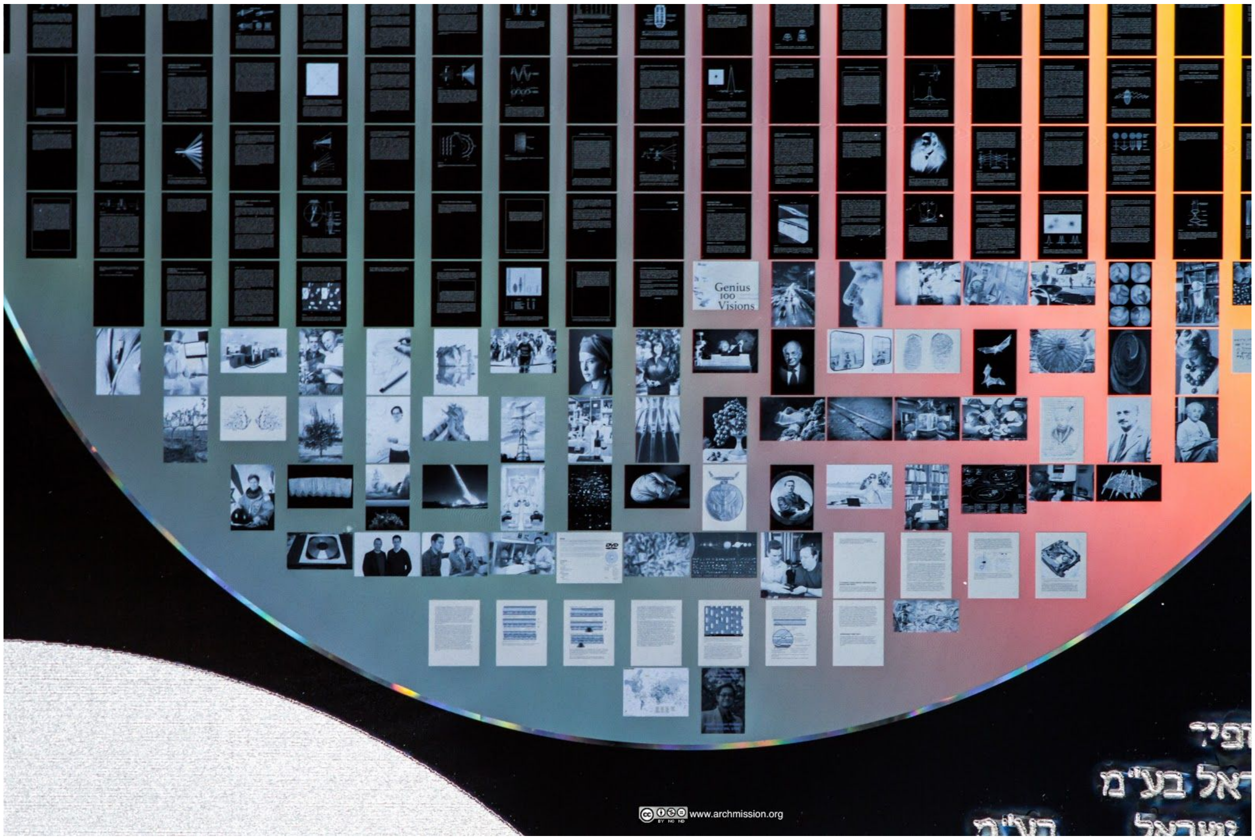
Caption: The glass master of the top layer (Front Cover) of the Lunar Library, produced at the start of the Nanofiche production process. The glass master is written at high speed using a patented polar-raster method, by NanoArchival at Stamper Technology. The content is etched by laser as nanoscale diffractives into the glass, at 300,000 dpi (dots-per-inch). From this glass master, a thin nickel foil is grown by electro-depositing the nickel atom-by-atom at the atomic scale. The resulting foil is then separated from the glass and further generations of nickel are then grown from that to produce the final Nanofiche disc.



Caption: Close up of the final product - a nickel Nanofiche disc containing 8 circles of high-magnification Primer Section data on ANALOG 2, of the Lunar Library

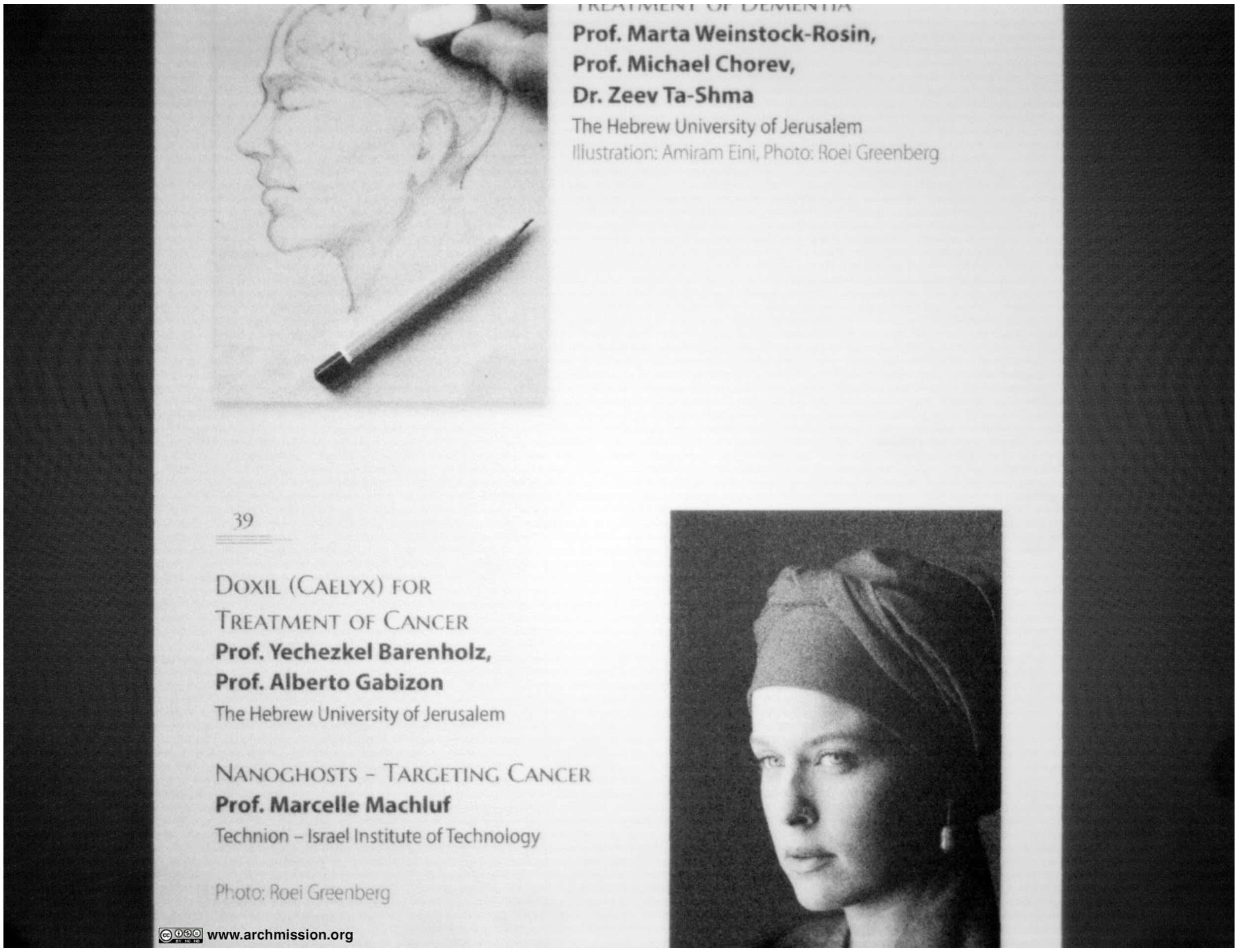


Caption: Zooming into one of the circles on ANALOG 1, containing Selections from the November 2018 Arch Mission and SpaceIL Websites, An Image of from The Voyager Disks, Lunar Library Architecture and Contents, Introductory materials and the technical specifications for the Lunar Library, and the start of the Israeli Time Capsule.

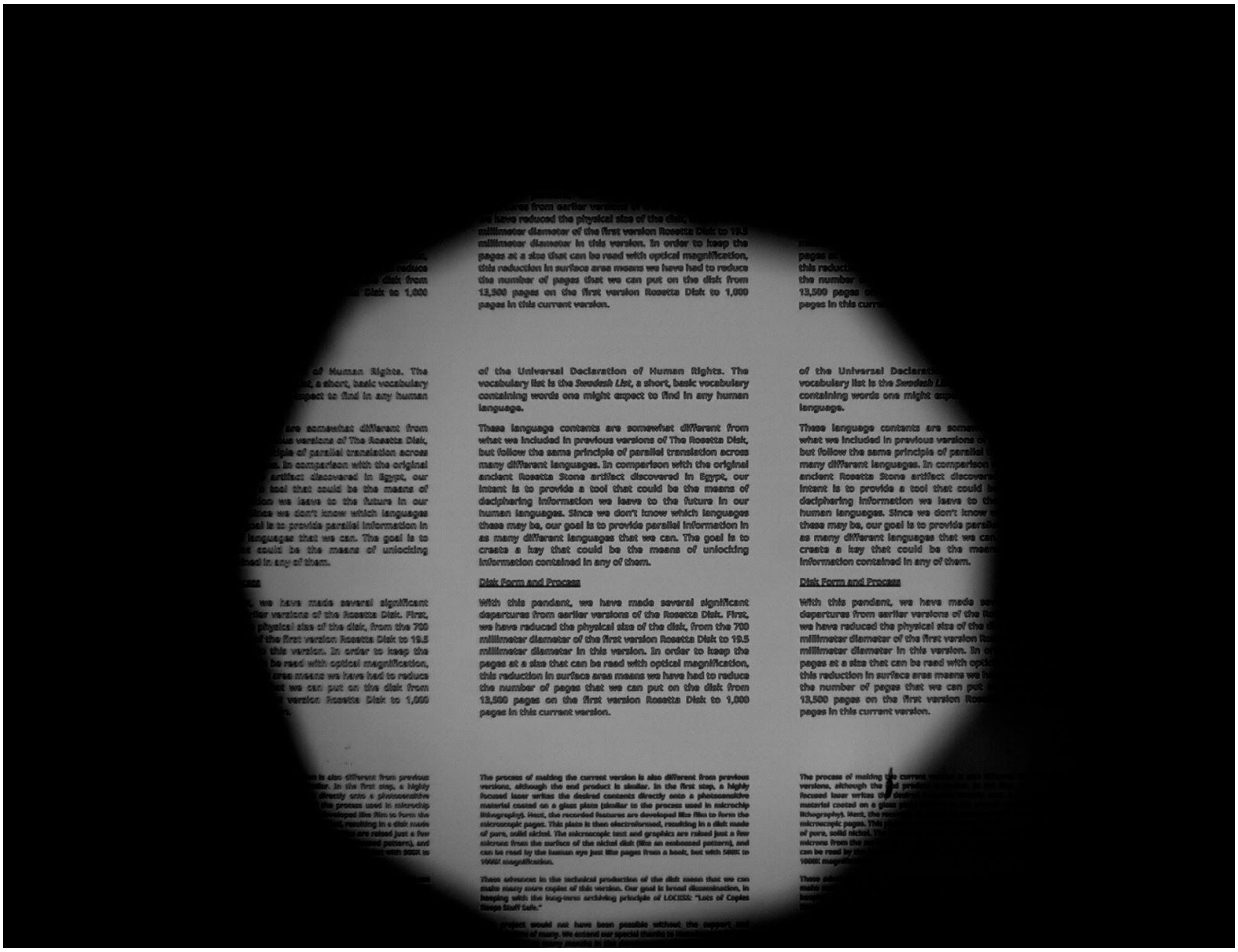


Caption: Zooming into one of the circles on Analog 1, containing a portion of the The Israeli Time Capsule

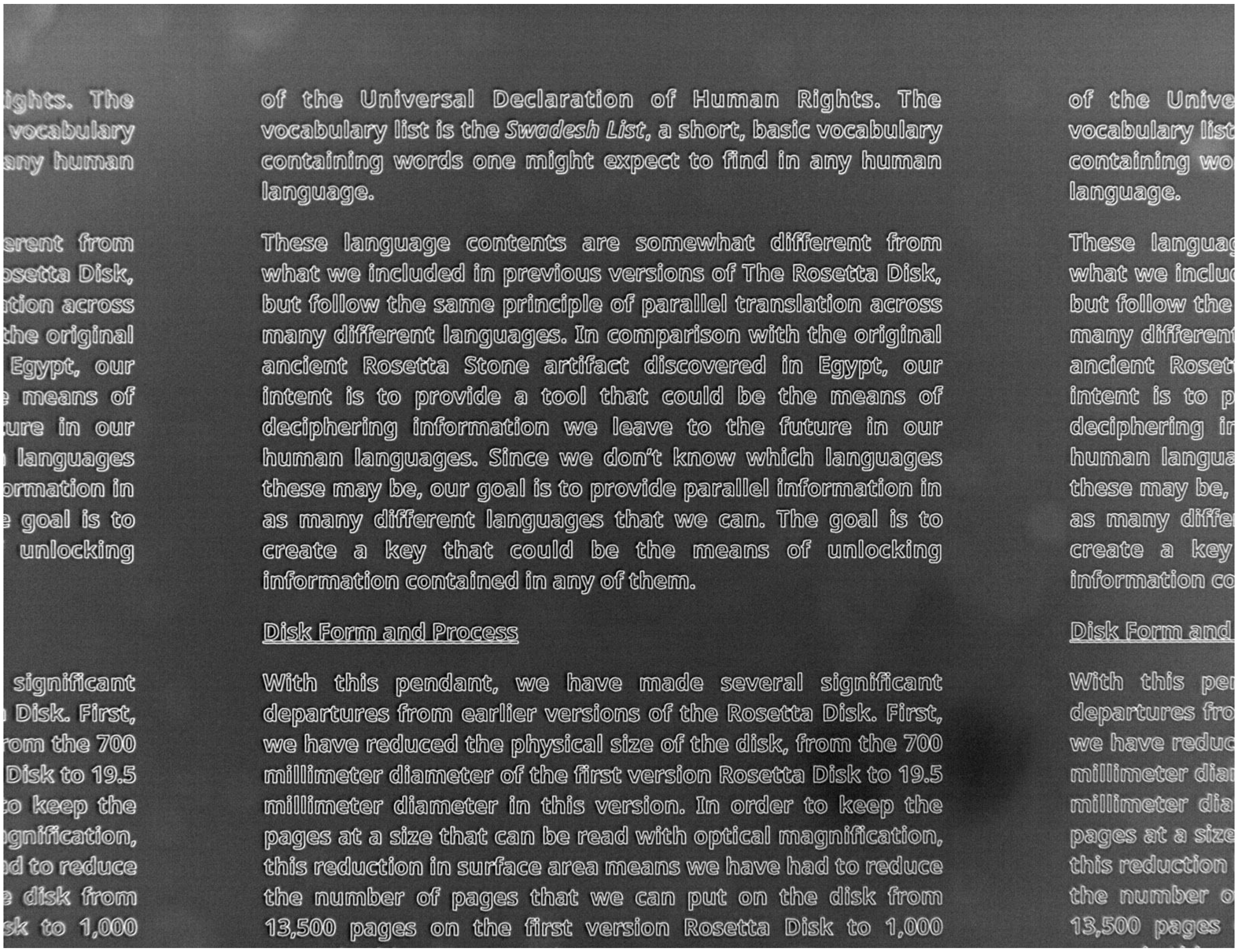
Caption: Nanofiche Retrieval System Image - Computer Controlled Optical Microscope. Zooming into one of the circles on Analog 1, The Israeli Time Capsule, Israeli Discoveries and Developments That Influenced the World -- an Exhibition by the Israel Ministry of Science and Technology



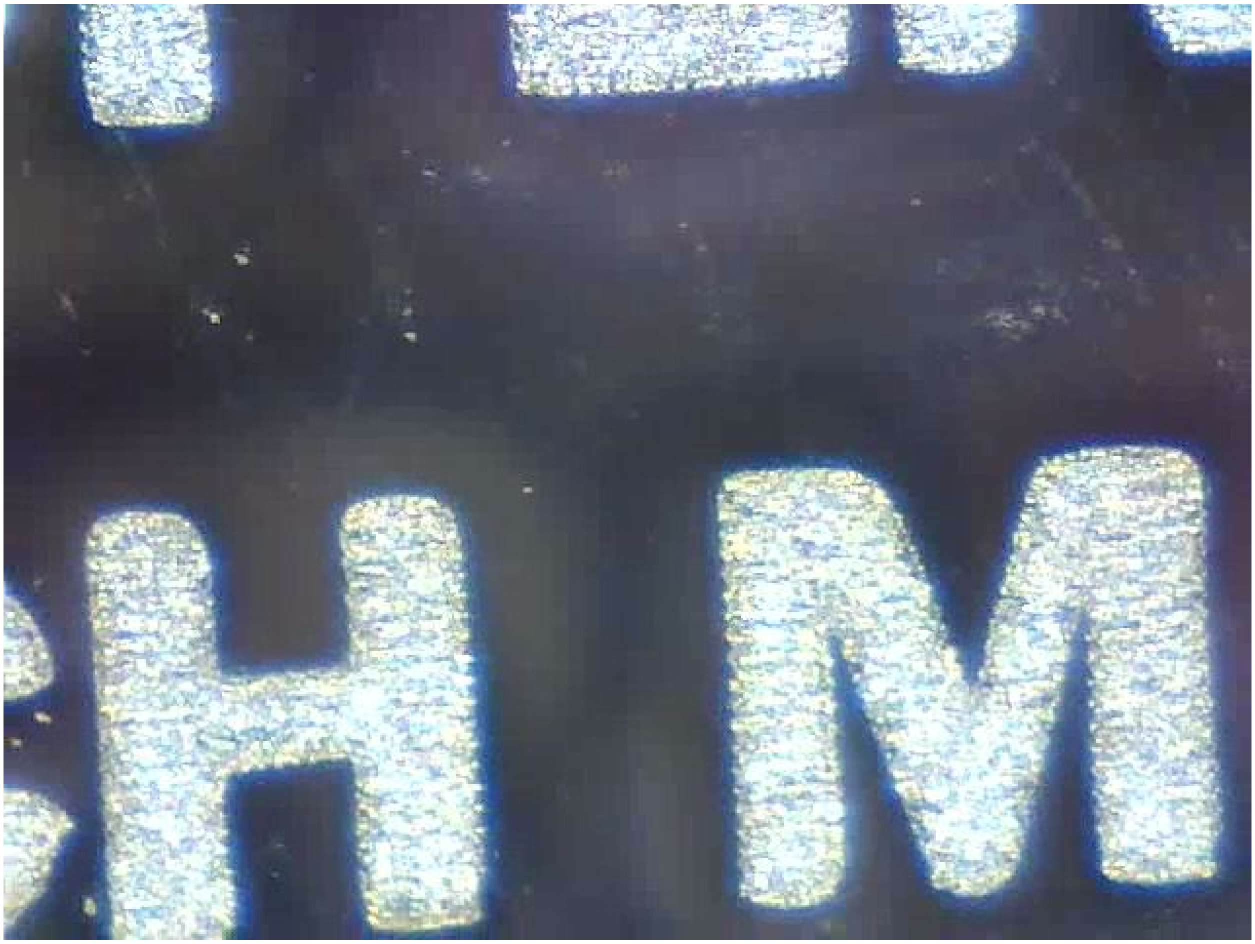
Caption: Nanofiche Retrieval System Image - Computer Controlled Optical Microscope. Zooming into one of the circles on Analog 1, The Israeli Time Capsule, Israeli Discoveries and Developments That Influenced the World -- an Exhibition by the Israel Ministry of Science and Technology



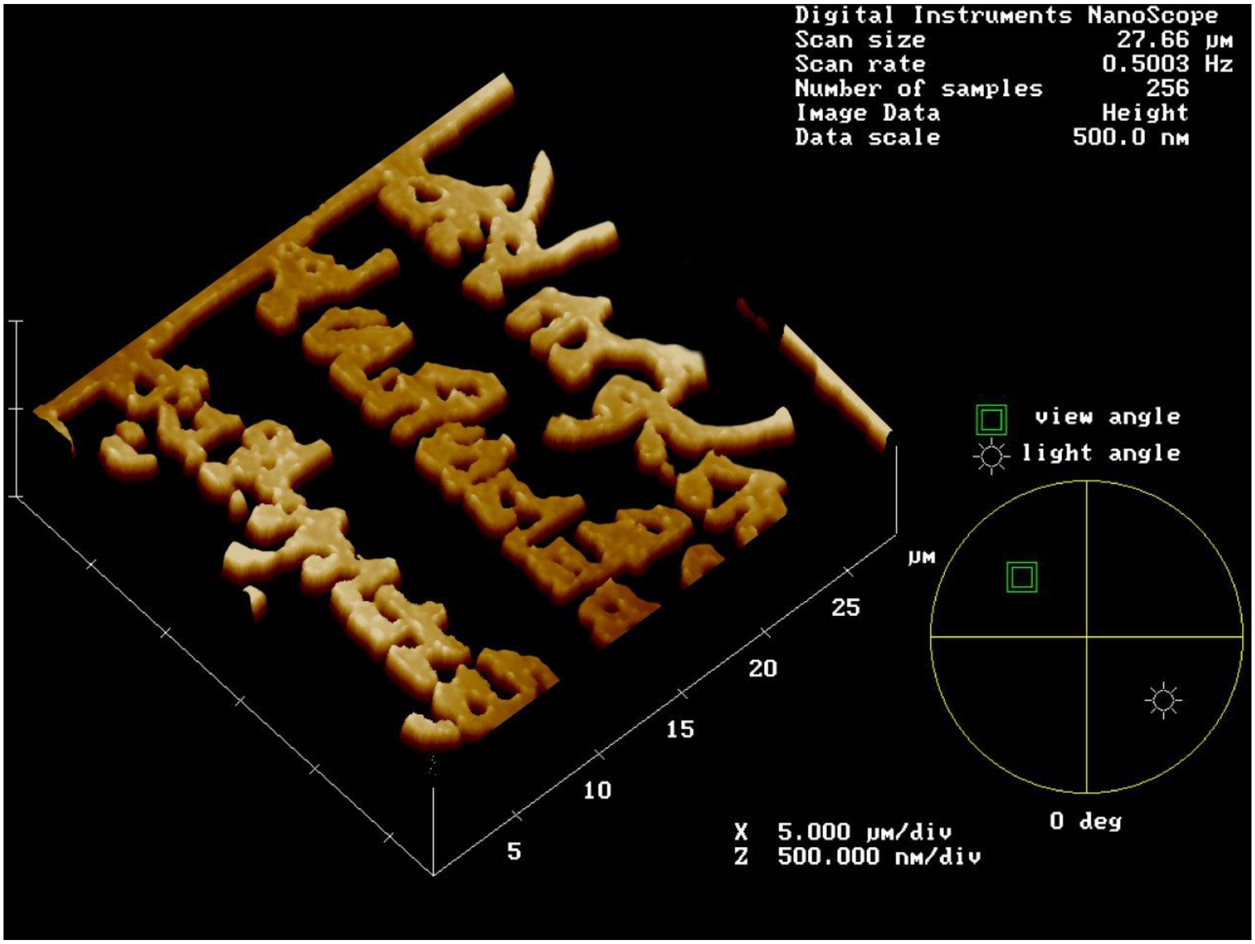
Caption: Microscope image of a selection of content in the Lunar Library - in this case content from The Wearable Rosetta, contributed by Laura Welcher, our partner and advisor, at Long Now Foundation.



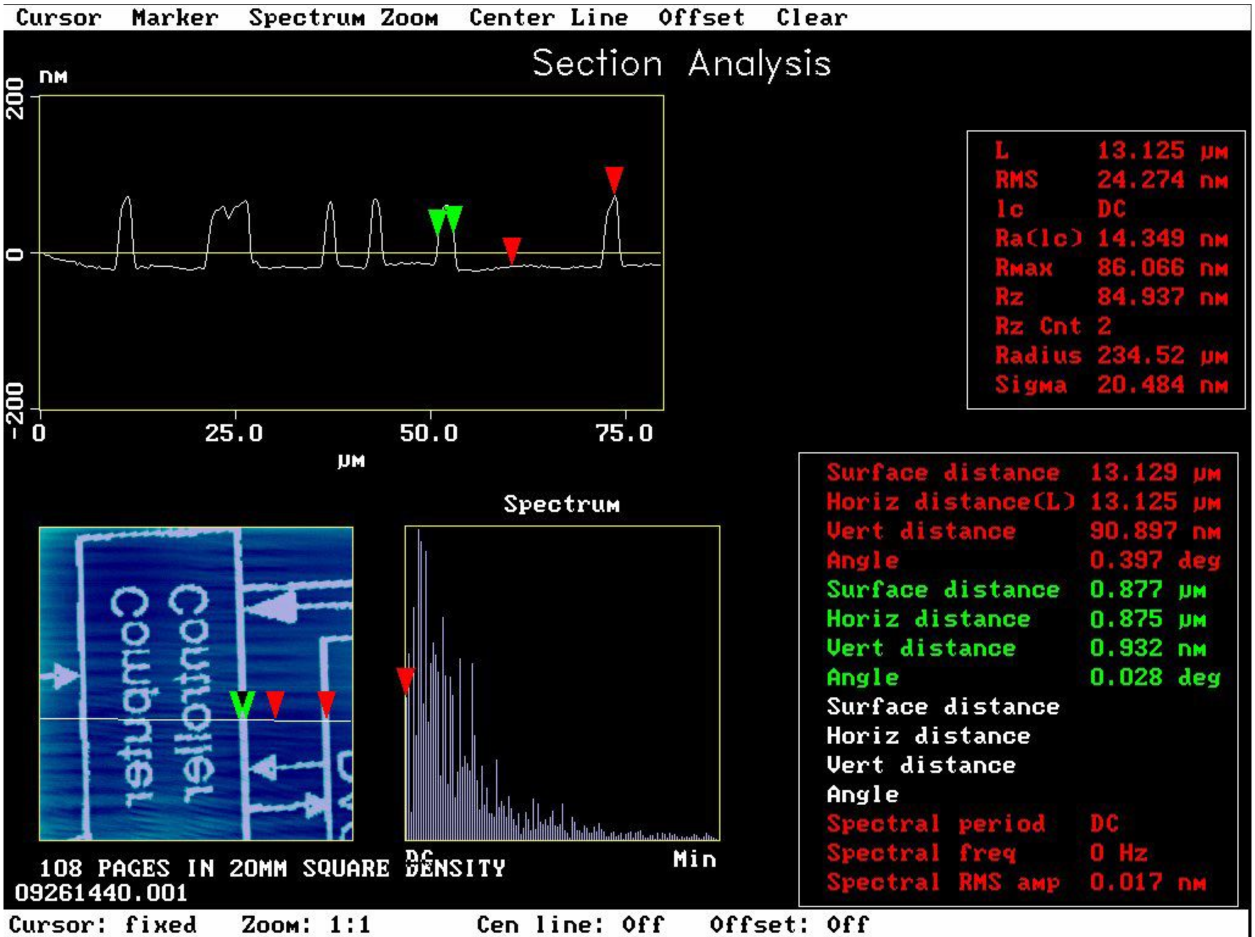
Caption: Higher magnification microscope image of analog content in the Lunar Library from The Wearable Rosetta, contributed by Laura Welcher, our partner and advisor, at the Long Now Foundation.



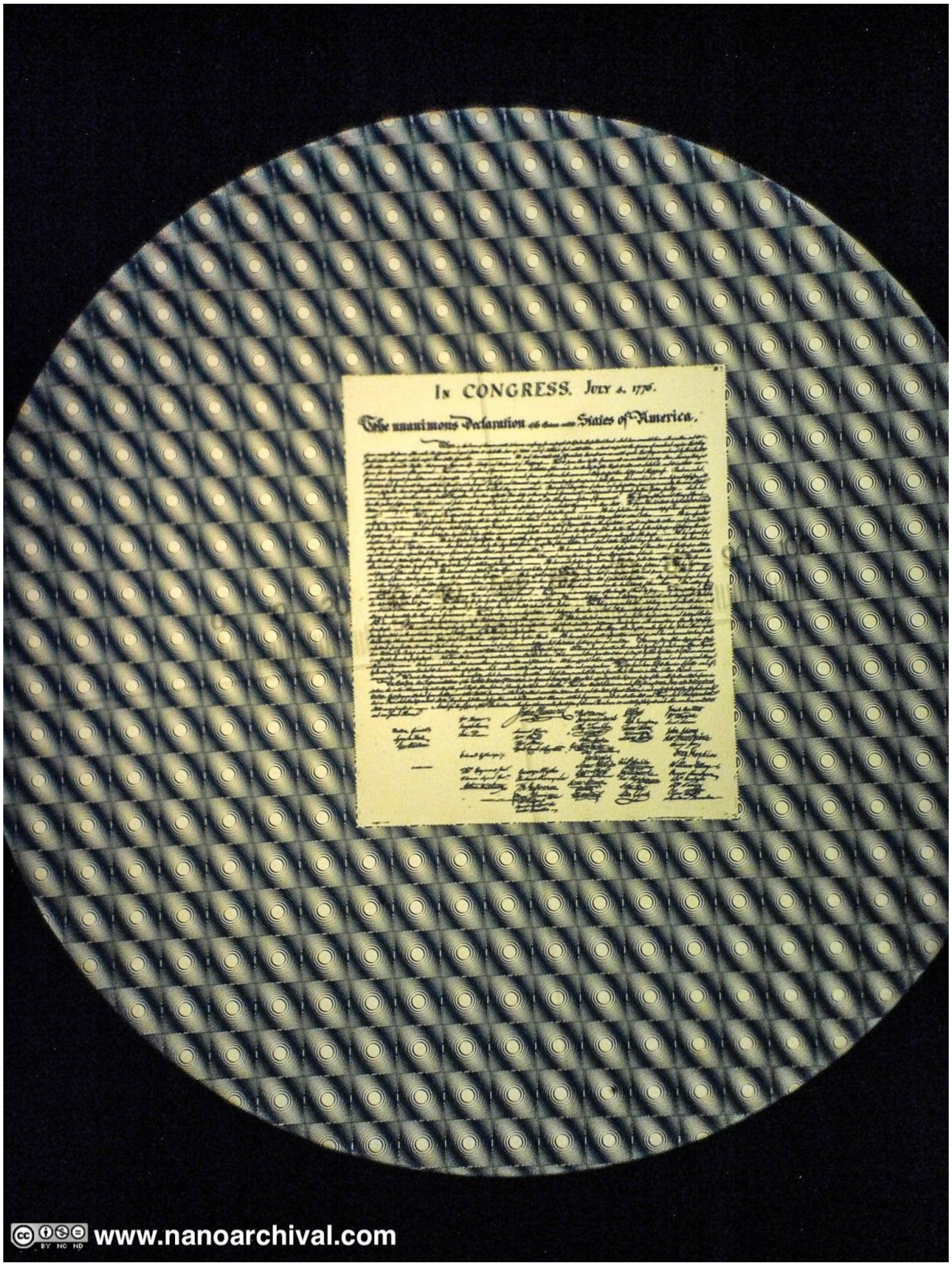
Caption: Higher magnification (but relatively low optical quality microscope image) of text etched into the surface of the Lunar Library. Here we see 4 micron tall letters etched into a nickel, in the analog layers but the optical quality of the scope does not reveal the 3D structure of each letter. With higher-quality optics, the letters can be seen to have 3D structure with very defined and clear edges and no noise or distortions between them. In deeper magnification layers of the analog sections the letters are only 1 micron tall.



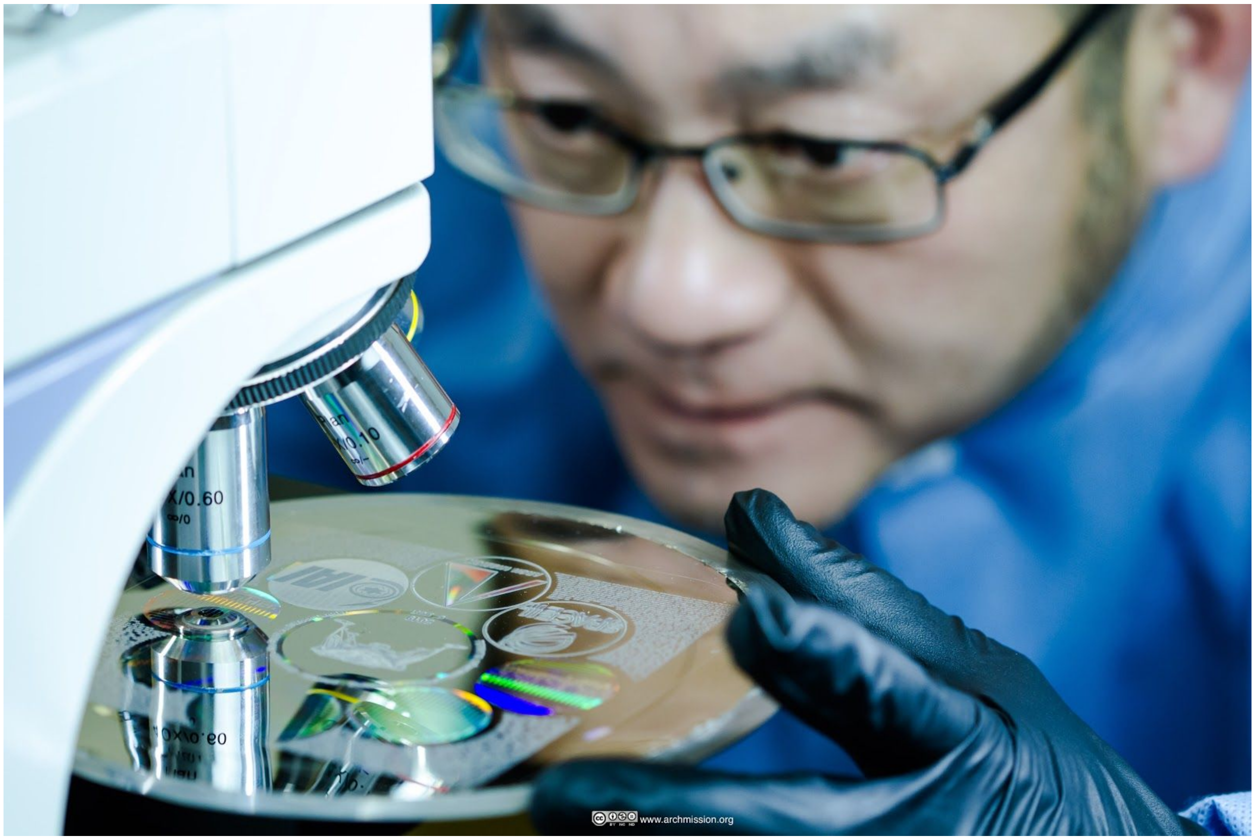
Caption: 3D rendition of a 25 micron width area of a piece of Nanofiche, generated by an atomic force microscope (Digital Instruments NanoScope). The letters themselves are seen to be raised surface indicia. The letters are literally 3 dimensional structures in surface relief, on a scale of a single wavelength of light, that rise up from the nickel substrate plane (the black area between the letters). All the analog content in the Lunar Library is structured like this. This is similar to an old fashioned typesetting block - such as print leading, and woodblock printing forms, but at nanoscale and in nickel. Using this structure we can grow generations of duplicates (in reverse, and then reversed back) in nickel. It is also possible to print from these nickel master structures directly to polymer film, using injection molding or roll-to-roll printing, for higher volume applications.



Caption: Atomic force microscope image, capture from a glass master for a sheet of Nanofiche images of the patent for the technology used to create Nanofiche -- This shows a reversed image of the words “Computer Controller” on glass, before it is etched to nickel (when it will then appear in the proper orientation). A glass master is the first generation that is created during the production of Nanofiche. This diagram shows that the etched lines in the mastered image are in the sub-micron range.



Caption: Image showing example of preservation of important documents in Nanofiche. Many such documents are collected and archived in the Lunar Library in this manner.



Caption: Bruce Ha, MSEE, inventor of Nanofiche, inserting the nickel cover layer of the Lunar Library into a metallurgical microscope stage for surface quality inspection during the production process. The entire surface of each disc was extensively tested to ensure all the data was properly etched. Different types of microscopes and other technologies are used during the QA process.

Caption: Optical testing of the high-magnification analog data etched on one of the top analog layers of the Lunar Library prior to laser cutting. The colorful rainbow light on the surface is due to diffractive patterns etched into the disc. The data is rendered as single-beam software-generation holograms that are then written as nanoscale diffractives by laser onto a glass master. The patterns on the glass are then electro-deposited to nickel films at atomic scale to make nickel masters. From the masters several generations of nickel films are then made to generate nickel duplicates, such as this disc being quality-tested for surface defects on the microscope stage in the image above.

ANALOG DISC 1 – THE FRONT COVER DISC

- 1500 IMAGES (Pages of books, photos, illustrations, etc.) rendered with 115.2 billion pixels per nickel layer.
- Viewable with 100X Magnification Optical Microscope. This level of magnifications has been available for 100’s of years and is easy to make.

THE ARCH MISSION FOUNDATION PRIMER, PART 1

- Teaches what is on the discs, how to access the content, and how to understand it.

HOW TO ACCESS THE LUNAR LIBRARY

- Technical explanations and instructions for how to access the deeper digital layers of data in the Lunar Library

ABOUT THE ARCH MISSION FOUNDATION

- www.archmission.org
- About us, our mission, team, advisors, partners, our work and projects.
- Specifications for the Lunar Library discs

ABOUT SPACEIL

- www.spaceil.com
- Website and other documents from SpaceIL and other sources about the mission

THE ISRAELI TIME CAPSULE

- The Hebrew Bible
- The Holocaust Memorial - Testimonials from the United States Holocaust Memorial
- Photos, essays, drawings, by SpaceIL team, benefactors and Israeli students and children
- Israeli Discoveries and Developments That Influenced the World -- an Exhibition by the Israel Ministry of Science and Technology
- History of Israel and the Jewish People
- Selections from Hebrew Wikipedia and English Wikipedia

A HISTORY OF ARCHIVING CIVILIZATIONS

- Summary of previous major time capsule initiatives; locations of time capsules around the world, including seed vaults and other critical backups on Earth, as well as all human data left in outer space.
- Pictures of the most ancient cave drawings on Earth (the first examples of what the Arch Mission is doing)

THE GENIUS 100 VISIONS

- Essays envisioning the future, written by 100 visionaries (www.genius100visions.com)

ANALOG DISC 2 – SPECIAL COLLECTIONS

- 20,000 Images @ 1000X Magnification, rendered with 115.2 billion pixels per nickel layer.
- Expanded Version Top Cover Layer
- Includes all Layer 1 content at much higher density, plus more content (books, manuscripts, photos and illustrations)

SPACEIL SPONSORS, HISTORY, COMMUNITY

- Photos and content from VIPs
- Photos and content from other contributors

ADDITIONAL PRIMER MATERIALS

- Higher magnification print of all items on Analog 1
- Digital Content Access Standards and Specifications
- Technical and Scientific Reference Library

ANALOG DISC 3 – THE ARCH MISSION FOUNDATION PRIMER, EXTENDED VERSION

- 20,000 Images @ 1000X Magnification, 20,000 Images, across 115.2 billion pixels.

THE ARCH MISSION FOUNDATION SPACEIL MISSION README

- Introductory content and orientation

THE ARCH MISSION PRIMER, EXTENDED VERSION

- Defines and explains ~1 million concepts in diagrams and sets of pictures and words, in many languages. Subjects include culture, history, geography, art, architecture, science, technology, anatomy, physiology, medicine, philosophy, psychology, economics, law, government, etc.

ARCH DEVICE SPECIFICATION

- Specifications for the Lunar Library Arch Payload.

WEARABLE ROSETTA

- Wearable Rosetta is a project of the Long Now Foundation which aims to collect information on the world's nearly 7,000 languages and create the Rosetta Disk which is an analog backup of the collection that can last for thousands of years. As many of the world's languages are endangered the project also stands as a testament to the world's linguistic diversity at the dawn of the 21st century, a picture which may greatly change in coming centuries. The first Rosetta Disk was completed in 02008. In 02016 a wearable version of the archive was created. This wearable version had 1,000 microscopic pages formed into a disk of nickel and contained the Preamble to the Universal Declaration of Human Rights as its main parallel text, and vocabulary from the PanLex collection as its main parallel wordlists. The entire content of the Wearable Rosetta disk is in the analog section of the Lunar Library, and comprises an important additional section of what we refer to as, The Primer. In the Digital sections of the Library, the Rosetta disk is also included along with the Full PanLex dataset.

MEMORY OF MANKIND

- Pages from the Memory of Mankind Project, and image of the Token artifact.

ARCH MISSION ADVISOR ARCHIVES

- Archives contributed by Arch Mission Advisors

ANALOG DISC 4 – ANALOG ARCHIVES, CONTINUED

- 20,000 Images @ 1000X Magnification, across 115.2 billion pixels.

WIKIPEDIA VITAL ARTICLES COLLECTION

- A 12,000 page printout of a subset of the English Wikipedia as of July 20, 2018, comprising several levels of the hierarchy of articles in the Wikipedia Vital Articles collection, as well as additional pages selected by The Arch Mission Foundation (space related topics, technology standards topics, etc.)
- Articles were printed out to PDF and then etched as analog page images onto the Nanofiche surface at 200 dpi.

SPECIAL COLLECTIONS

- English Language[7] Training Materials
- Computers and Semiconductors
- Arch Mission Private Collections
- Writing Systems and Character Sets.

PRIVATE COLLECTIONS

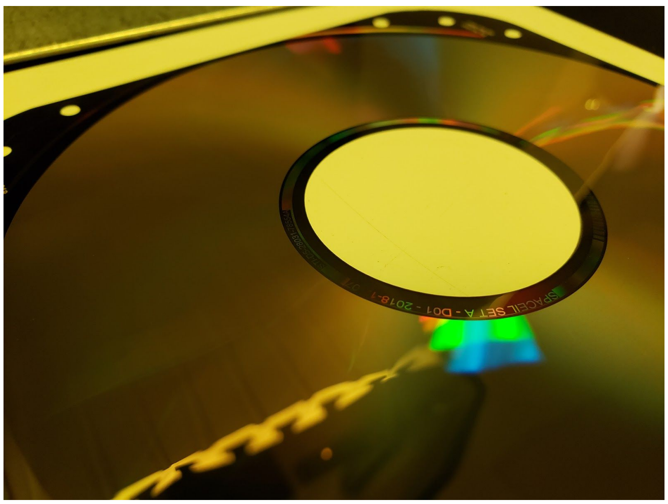
- Collections of documents, photos, illustrations, video, data sets
- Contributed by individuals, authors, publishers, organizations
- Includes collections of ancient, rare and historical documents, artworks, books, image collections.

[7] English is the language of reference in the Lunar Library. In addition, in other sections we include language learning materials for all major languages presently in use; in addition to Rosetta and PanLex

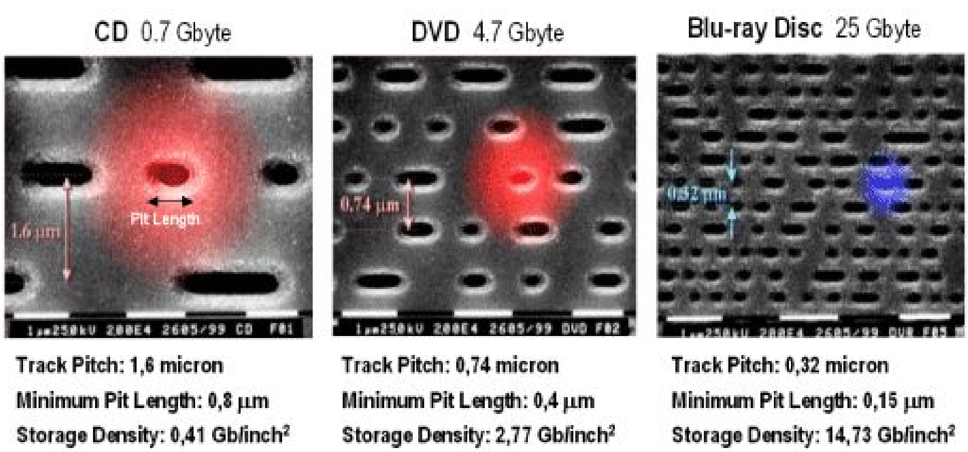
THE DIGITAL LAYERS

ABOUT THE DIGITAL LAYERS

- 21 digital Nanofiche discs
- Each 120mm disc is a 40 micron (0.04mm) thick DVD master encoded in nickel film
- Contains >100GB of highly compressed digital data archives; decompresses to ~200GB.
- Includes tens of millions of pages of information, as well as images, audio, video, and software.



Caption: One of 21 digital layers of the 25 layer Lunar Library -- The top 4 layers are encoded as analog images.



Caption: Images of the 3 dimensional nanostructures that comprise the actual data encoded onto different types of digital optical disks.[8]

[8] Source: http://blu-raydisc.com/en/WhatisBlu-rayDisc/HistoryofBlu-rayDisc/BDvs.DVD.aspx

THE ENGLISH WIKIPEDIA

- ~7.5 million printed pages, if printed out as 8.5*11 inch paper pages
- Full Digital Data Dump, as of July 20, 2017
  - Text and XML dumps only; media resources to be delivered on subsequent missions
- Page Images
  - Subset of top articles in Wikipedia (12,000 pages) printed out to PDF[9] files as well; These are also in the analog layers.

PROJECT GUTENBERG

- A large archive of books and media from a large online library of Copyright-free resources.

THE INTERNET ARCHIVE

- Selections from a large set of open access content and media. Documents, books, datasets, media resources, news resources.

THE WEARABLE ROSETTA

- Wearable Rosetta is a project of the Long Now Foundation which aims to collect information on the world's nearly 7,000 languages and create the Rosetta Disk which is an analog backup of the collection that can last for thousands of years. As many of the world's languages are endangered the project also stands as a testament to the world's linguistic diversity at the dawn of the 21st century, a picture which may greatly change in coming centuries. The first Rosetta Disk was completed in 02008. In 02016 a wearable version of the archive was created. This wearable version had 1,000 microscopic pages formed into a disk of nickel and contained the Preamble to the Universal Declaration of Human Rights as its main parallel text, and vocabulary from the PanLex collection as its main parallel wordlists. The entire content of the Wearable Rosetta disk is in the analog section of the Lunar Library, and comprises an important additional section of what we refer to as, The Primer. In the Digital sections of the Library, the Rosetta disk is also included along with the Full PanLex dataset.

THE PANLEX PROJECT

- PanLex is a project of the Long Now Foundation that is building the world's largest lexical translation database. Its goal is to include every word in every language. The PanLex Database contains 25 million words in 5,700 languages sourced from 2,500 multilingual dictionaries, totaling 1.3 billion directly attested lexical translations. It does not stop there: by transforming these dictionaries into a single common structure, the PanLex Database makes it possible to infer billions more translations

[9] All necessary technical specifications and file formats, and the necessary source code and compiled code are provided. The most essential info is taught in the analog layers as well.

that are not found in any single dictionary. PanLex data is included in the Rosetta Wearable Disk in analog form.

- The PanLex dataset is included in its entirety in digital form in three copies in different formats: .csv, .json, .sql. All the necessary technology specifications for these formats are provided in the digital layers, and all necessary knowledge for accessing the digital layers is in the analog layers.

WORLD FACTBOOK

- The entire Website of the World Factbook, as of July 07, 2018. The World Factbook provides information on the history, people, government, economy, geography, communications, transportation, military, and transnational issues for 267 world entities.
- Includes maps of the major world regions, as well as Flags of the World, a Physical Map of the World, a Political Map of the World, a World Oceans map, and a Standard Time Zones of the World map.

TYPE AND FORMAT COLLECTIONS

- The complete content of fileformats.com
- The complete content of ancientscripts.com
- The complete content of evertype.com

FEATURED AUTHORS

- To be announced

PRIVATE COLLECTIONS

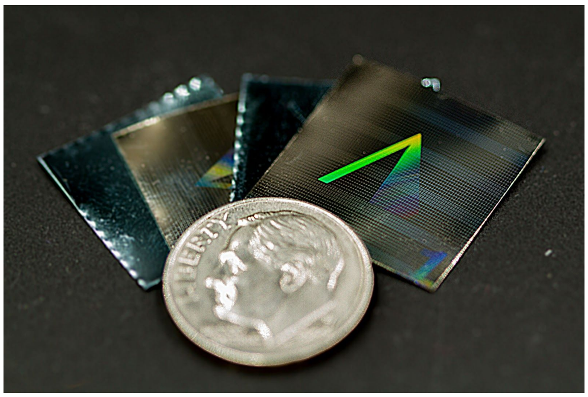
- Tens of thousands of books, periodicals, documents, software applications, media files, photos, illustrations, Web sites, data sets, and more.
- All subjects, cultures, nations, languages, genres, time periods are included.
- All major languages and a broad cross-section of perspectives.

THE VAULTS

The Lunar Library contains special collections of special content, some of which may be opened in the future. Follow us at @archmission and we'll keep you posted. We will add to this document if and when any of these are revealed.

Appendix 1 -- Nanofiche Fact Sheet

About the Nanofiche Archival Technology



NANOFICHE: SPACE-AGE ARCHIVAL STORAGE

The Arch Mission Foundation chose a new technology — nickel based films of Nanofiche — for the Lunar Library.

We helped to develop Nanofiche, and then chose to use it, because it is ideally suited to preserving large amounts of analog format information in the harsh environment of space and the surface of the Moon.

When it comes to preserving data in extreme environments, such as outer space, the surfaces and atmospheres of planets, or underground or underwater, there really is no alternative to Nanofiche today.

There is no other archival technology that we know of that is space-grade, lightweight, highly durable and efficient, and ready for prime-time today. Nanofiche is the only viable solution for these scenarios.

What is Nanofiche?

Nanofiche is a new analog archival preservation media that overcomes the limitations of existing technologies.

Nanofiche is written into nickel films, of 20 to 40 micron thickness, that can be cut into any desired shape, most commonly as rectangular or circular sheets.

Data is etched into Nanofiche by optical nanolithography, using an electroforming process.

Unlike other alternatives, nickel-based Nanofiche never degrades and never has to be replaced.

Nickel does not oxidize, has no half-life, and can withstand electromagnetic radiation, high heat, extreme cold, and exposure to the elements, microbes, and many types of chemicals, for thousands of years or longer on Earth.

Nanofiche can store up to 2,000 analog pages of text at 150 dpi, per square centimeter. For example a 20 x 20 mm nickel Nanofiche sheet can hold up to 8,000 pages of text rendered at 150 dpi.

At this resolution, a letter-size page of Nanofiche would hold up to 1.2 million analog images and pages of text!

If the content to be preserved contains photos, then the output must be rendered at double the resolution (300 dpi) to reduce pixelation and increase image quality. Because photos are rendered to Nanofiche in grayscale diffusion dithers, it effectively reduces the capacity from 1.2 million analog images, to 300,000, per letter-size sheet of Nanofiche.

For greater image quality, at 600 dpi, Nanofiche can still hold an impressive 150,000 analog images of pages and photos, per single 8.5”x11” sheet.

It also worth noting that Nanofiche primarily stores data in analog format, but can also be used to encode digital data for archival preservation as well — either as analog images of digital bitmaps, or in native digital formats (such as DVD format).

Why Is Nanofiche Necessary?

The Pyramids and the hieroglyphics they contain are still readable, thousands of years after being built and abandoned. But, ironically, for all our advances, our civilization’s records are far more delicate than those of ancient civilizations that used stone and metal to capture their knowledge.

If there was a national or global catastrophe, the majority of our knowledge and data would be immediately inaccessible, and then gone without a trace in 50 years or less. Within a few decades to a few hundred years after such an event, all our paper records would decay as well, leaving only dust.

The Ephemerality Of Digital Data

The digital data that our present-day civilization depends on is stored in, and accessed with, plastic and other unstable materials. These materials oxidize and decay in only a few decades or less, or even faster if exposed to water, chemicals, or extreme temperatures.

The computer equipment and electronic devices that power the world - from phones to the server farms that drive the Internet and all major corporations and governments, are also highly vulnerable to electromagnetic radiation. In the event of a major solar storm, or an EMP attack, nuclear blast, or high energy cosmic energy burst, anything not protected by military-grade shielding would be lost.

And then there are all the ordinary risks, like loss of power, power surges, fires, floods, and other natural disasters that can destroy or prevent use of our information technologies and storage media.

In short, our digitally-dependent civilization's technologies make it increasingly vulnerable to a variety of risks.

Microfiche: 1960's Archival Technology

The only sure-fire way to guarantee that important information can be recovered in the event of a catastrophic event, is to back it up with specialized archival media that are designed to survive and be recoverable, even without access to computers and electronics.

The preferred technology for critical long-term backups is analog archival storage. However, today nearly all such storage uses an decades-old film-based media called microfiche. Microfiche is a fragile, film-based media, invented in 1961, that stores data as optical images on film — literally, tiny photographs.

Microfiche is created using camera systems and retrieved using mechanical optical microfiche readers that, if you are over 30, you may have encountered in a library when you were in school.

The Weaknesses Of Microfiche

While microfiche is certainly more durable than any form of paper or magnetic media, and even most optical media, it is delicate, perishable, costly to maintain, and takes up far more physical space than Nanofiche.

Microfiche is sensitive to environmental conditions and must be carefully maintained. It is vulnerable to humidity, heat, and water damage. It requires HVAC to maintain a proper temperature and humidity environment to preserve it. Sustained loss of power that disables HVAC, or damage from natural disasters such as floods, can result in total loss or damage that requires costly replacement or salvage operations.

Microfiche has a life expectancy of 400 to 800 years, if maintained continuously under ideal conditions. However most State Archives only certify microfiche for 25 to 50 years, after which point a new copy of the media must be generated to be certain that records are preserved. . Microfiche is also not very space efficient compared to today's digital media. Microfiche typically stores 0.4 pages per square centimeter.

A typical sheet or card of microfiche is 3” x 5” or 9 x 12 cm and contains 40 pages of text, with a reduction equivalent of about 25 times.

A letter size format sheet of microfiche would hold only about 250 pages of text, compared to up to 1.2 million pages of text in Nanofiche. While there are some forms of microfiche that can store slightly more pages per sheet, they are not widely used and are still not comparable to Nanofiche ’s capacity.

Due to the dual necessities of HVAC and replacement, and the physical space requirements of microfiche storage, and the need for old-fashioned microfiche readers, the total cost-of ownership of microfiche grows with time

Who Makes Nanofiche?

Compared to the weaknesses of microfiche, Nanofiche offers a compelling new alternative that is perfectly suited to the exotic needs of the Arch Mission Foundation. But it may also have value across a broader range of organizations, from governments to large commercial corporations and nonprofits that need to protect large amounts of critical information against all scenarios.

If there is one weakness of Nanofiche today, it is that it is a new medium, that is only supplied by a single vendor.

Based on extensively studied and tested technology, studied by Los Alamos National Laboratories, Nanofiche is not yet supported by an industry of suppliers and aftermarket service providers. However, this may develop over time as the benefits of this technology are understood.

Nanofiche is a patented, proprietary product of NanoArchival, the first commercial spinout from The Arch Mission Foundation’s non-profit research and innovation initiatives.
The technology underlying Nanofiche is based on the inventions and technology of Arch Mission Foundation advisor, Bruce Ha, Senior Research Scientist, and former head of Kodak Optical Disc division, who invented the hybrid Picture CD technology.

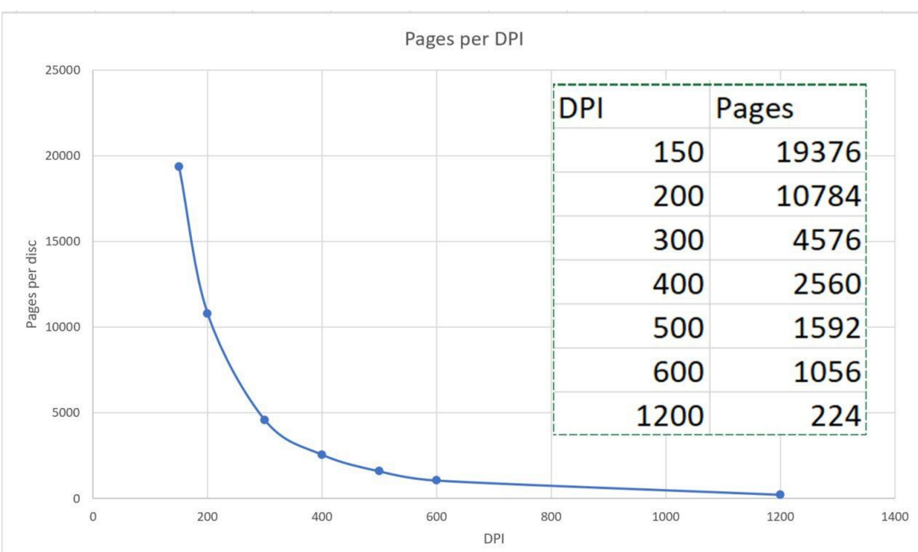
In exchange for helping to incubate NanoArchival, the ArchMission Foundation is a small founding equity partner in the venture. It is hoped that, if NanoArchival is successful, the venture will become a source of financial support and endowment to the Arch Mission Foundation in the future.

This incubation model is similar to other non-profit/for-profit spinout innovation incubators, such as the model at SRI Ventures (Disclosure: Arch Mission co-founder, Nova Spivack helped to develop and build the SRI Ventures incubator).

NANOFICHE VS. MICROFICHE

Storage Capacity

- Up to 1000X more space efficient than microfiche
  - Nanofiche can store up to 2,000 analog pages of text at 150 dpi per square centimeter. For example a 20 x 20 mm nickel sheet can hold up to 8,000 pages of text rendered at 150 dpi. At this resolution a letter size page can hold up to 1.2 million pages of text.
  - If content contains photos, the output must be rendered at double the resolution at 300 dpi to reduce pixelation and increase image quality as the photos are rendered in grayscale diffusion dither effectively reducing the number of pages to 300,000 per letter size format. At 600 dpi, 150,000 pages can fit on a single 8.5”*11” sheet of Nanofiche.
  - Microfiche can store 0.4 pages in a square centimeter. A typical microfiche is 3” x 5” or 9 x 12 cm. An average microfiche contains 40 pages of text with a reduction equivalent of about 25 times. A letter size format of a microfiche would hold about 250 pages of text.
- Lightweight and thin
  - Nanofiche can be as thin as 20 to 40 microns per sheet, or can be printed into thicker sheets if desired.
  - A 120mm disc of up to 40,000 pages weighs only 4 grams
  - Can be cut into any shape (tape, disc, sheet, etc.)



DPI	Pages
150	19376
200	10784
300	4576
400	2560
500	1592
600	1056
1200	224

Caption: Number of analog images or pages per 120mm disc of Nanofiche, as a function of resolutions (DPI).

Caption: Analog images of Bruce Ha, MSEE, inventor of Nanofiche, at levels of magnification on Nanofiche.

Durability

Write-Once

- Nanofiche never has to be replaced. It does not decay and is not affected by humidity, temperature, microbes, or radiation.
- Microfiche has a life expectancy of up to 800 years, under ideal HVAC-controlled conditions. However most State Archives only certify microfiche, for 25 to 50 years, after which point a new copy of the media must be generated. Therefore, the total cost-of ownership of microfiche over long periods can be large.

Ultra-Long Duration

Nickel Nanofiche

- Nickel lasts for at least tens of thousands of years on Earth, or forever, if properly protected.

- Nickel lasts for up to billions of years in space and/or on other planets, if properly protected.

Polymer Nanofiche

- Nanofiche can be replicated from nickel to polymer any number of times, inexpensively. Polymer lasts for 400 to 700 years.

Durable over a wide range of environmental conditions

Does not decay

- Pure 100% nickel; Nickel has no half-life; it's a stable element; it lasts forever
- Nickel is used in ocean motors and in rockets because of its properties.
- Stainless steel only needs 7% of nickel to make it not rust
- Hard metal that is difficult to damage physically
- Withstands exposure to a wide range of chemicals
- Does not oxidize
- Contains no carbon-based materials
- Biological organisms cannot consume or damage it

Difficult to damage

- Not affected by radiation, heat, cold, humidity, moisture or even immersion in freshwater; salt water can gradually affect it but even after many thousands of years of constant salt water exposure, the content is retrievable.
- Still readable even after thousands of years exposed to oxygen or submerged in water
- 2000 degree Fahrenheit sustained direct heat from a blowtorch will not damage it
- Electric and magnetic fields have no effect on it
- Strong radiation from nuclear blasts, high energy cosmic rays, or electromagnetic pulses will not damage the content
- Designed to preserve information in case of nuclear war (Studied by Los Alamos National Laboratories; extensively tested)

Ease-of-use

Easier to handle

- No special handling or storage requirements
- Supports both analog and digital data formats
- Copies can be easily replicated from a master to more nickel copies or to any metallic foil, or inexpensive polymer materials

Versatility

- Can be integrated into a wide range of products and form-factors
- Can be encrypted and authenticated
- Can be retrieved optically without a computer; just needs sunlight and lenses in worst-case

- Can be automatically retrieved and processed electronically in computerized Nanofiche Retrieval devices.
- Nanofiche is integrated with software retrieval and is fully electronically searchable and can integrate with CMS and workflow systems.

Cost-of-ownership

Less expensive

- Costs to create Nanofiche are comparable to microfiche, but costs to maintain it are dramatically lower than microfiche.
- The longer Nanofiche is stored, the lower the total cost of ownership becomes, compared to microfiche.
- Microfiche has a life expectancy of up to 800 years, under ideal HVAC-controlled conditions. However most State Archives only certify microfiche, for 25 to 50 years, after which point a new copy of the media must be generated.
- Nanofiche lasts virtually forever and costs nothing in energy to store, compared to microfiche which has to be maintained by HVAC in temperature and humidity controlled environments.
- There is a vast savings in energy cost to maintain Nanofiche versus microfiche, even over short 50-year durations.

HOW NANOFICHE IS MADE

Nanofiche is created via a proprietary a nanotechnology process by NanoArchival (www.nanoarchival.com).

1. Content is first scanned and digitized to digital images or files.
2. The content is then rendered mathematically into software-generated single-beam diffractive elements.
3. Next the content is etched into glass as 300,000 dpi diffractive patterns using a laser.
4. From the glass master, pure nickel is electro-deposited to the content to create foil masters that can be viewed optically (naked eye, magnifying glass, microscope, special computerized scanner)
5. The nickel foil masters can be duplicated to nickel or to other metallic films for ultra-durability (> 10,000 years), or to polymer films (~400 years)
6. Once duplicated, Nanofiche can be cut or molded into any shape (squares, sheets, tape, discs, etc.)

Appendix 2 -- Arch Discs - Technical Specification

(This document is available as a separate PDF file, here)

https://www.dropbox.com/s/w0ki9kfdhap1323/Arch%20Technical%20Appendix%20V3.5ns.pdf?dl=0

Appendix 3 -- Further Discussion

Who Are We Designing For?

One of the most important decisions in a project as ambitious as The Billion Year Archive is how to constrain it to a target audience. We can't design for all possible potential types of recipients and scenarios in the future. We have to decide who we want to communicate with and what range of scenarios they might occupy at the time they recover an instance of the Archive[10].

Our intended audience is future "human like" beings -- humans or their evolutionary offspring, or non-human beings who are at least functionally equivalent to humans in their sensory and cognitive capabilities, and who are located within our solar system at the time they encounter an instance of the Billion Year Archive.

We are not designing for beings who are not at least functionally equivalent in intelligence, language and visual senses to humans. If they are not as intelligent as humans, if they don't have language, and if they don't have visual systems and brains that can process images and linguistic symbols, then they are out of scope[11].

We are not designing for the inhabitants of another star system, although it is possible that if beings originating outside our solar system exist, they may visit our solar system and might encounter an instance of the Archive. We assume that any species intelligent enough to travel to our solar system from another star is more advanced than we are and is certainly qualified to understand the technologies we use to build Arch Libraries.

Within the class of beings who are in the scope of our design thinking, our primary intended future audience are scientists, archeologists and historians, or those in need of the knowledge of the past at that time.

We also note that we are designing for beings who, as a civilization, have attained at least the stage of development where they have invented simple compound microscopes (equivalent to the 1600s in our history).

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[10] Instances of the Archive are called Arch Libraries, Arch Discs.

[11] They are out of scope for this generation of The Archive, but it is an interesting subject for research to explore in future iterations. There is good work going on in the area of SETI and active SETI on this topic.

Arch Libraries on Earth

We are starting an initiative to install Arch Libraries in long-term locations on Earth as well as in outer space. Our Earth Library initiative seeks to design specialized containers that can preserve backups of our civilization on million-year timescales (or longer), for the possible benefit of intelligent beings in the future on Earth.

Our Earth Library missions seek to place Archs in deep natural cave systems, as well as underwater locations, and even deep underground storage vaults. These locations are selected to be inaccessible today, but likely to be rediscovered in the distant future, because of their locations and the geologies they are in.

Assuming that intelligent hominids -- or the equivalent -- reside on Earth in the distant future, another consideration in our design thinking is their level of technological advancement. We cannot be certain that they are as advanced as humans are today.

While we primarily are designing for at least a microscope-bearing civilization equivalent to our civilization as it was in the 1600s era of our past, there are edge-cases where our devices might be found by civilizations that are still at an earlier stage of development.

For example, it is possible than in 500 million years, after our present-day civilization and our species are long-since extinct, that primitive hominids may re-evolve here on Earth.

What if one of these future “cavemen” were to discover one of our Arch Libraries? How could we provide that caveman with value? How could we indicate to them that our artifact is special and should be treasured and handed down?

For a very low level of technologically recipient, we probably cannot communicate much knowledge, but at least we have a chance of communicating that the Arch Library itself is special through aspects of the design of the physical artifact.

To a primitive human the experience of the smooth, reflective, diffractive, highly organized and novel symbol-covered surfaces of an Arch Library might be a shocking and possibly mystical experience. An Arch Library would be so different from the wood, stone and animal based materials of their daily lives that it would be a major discovery for them.

If they don’t immediately discard it or ignore it, then they might keep the artifact as a precious object, and perhaps even ascribe it with magical powers or think it was a gift from the gods . They may admire its aesthetic beauty and keep it as an ornament or object of worship or power and hide it again.

If any of these happen then they might intentionally or inadvertently help us to preserve and pass it down through time, until someday in their far future, when their ancestors advanced

enough, someone qualified might eventually find the artifact and recognize its actual purpose and content.

Of course, all of this speculation if the future inhabitants of our planet don't have eyes, or if their intelligence is so alien that they cannot relate to any of our sensory experience and form of intelligence, or if they are so large or small that they can't even sense or relate to the artifacts and data in our Archives.

There are many ways that we can fail to communicate with beings in the future, or with aliens if they ever arrive here. But since we cannot anticipate most of these edge-cases, we are not attempting to solve for all of them.

We have to make certain broad assumptions about who our target audience is, and what they are capable of, in order to have enough constraints to design a teaching system that can actually be deployed in our lifetimes.

Although there is some chance that our assumptions could be completely wrong, it is not unreasonable to assume that any future "humanlike" intelligent lifeforms that evolve on Earth, will do so in Earth's level of gravity, and with an Earth-like atmosphere, and probably some microbial ancestors of Earth-life that may cause it to have much in common with our species.

On the other hand, we could be completely wrong. Humans could be unique throughout the universe, and perhaps in fact dolphins are much more likely to evolve on this water planet than humans in the future.

But again, we cannot solve for all possible audiences -- we have to make reasonable assumptions of what audiences are likely, or at least hoped-for, and constrain our design for them. "Humanlike" intelligence, may or may not be a common occurrence on Earth or in the universe, but we have to start with what we know.

Finally, although we are not able to anticipate all forms of life that may evolve or arrive on Earth in the distant future, it is probably reasonable to assume that if it is a spacefaring civilization, it will have a level of intelligence and technology sufficient to analyze ancient archeological relics such as the Arch Libraries we are leaving for them today.

How Can We Prevent Recipients from Damaging The Archives?

Ironically one of our greatest challenges is not to deliver Arch Libraries to beings in the distant future, it is to prevent them from accidentally or intentionally damaging or destroying them before they can extract the knowledge they contain.

The nickel surfaces of Arch Library discs are easily bent and scratched, which can damage or destroy the nanostructures etched on their surfaces. With effort they can also be torn or crushed.

To protect Arch Libraries from these kinds of external factors we have a few choices. One choice is to use redundancy: assume that most copies of the Arch Libraries on Earth won't make it without being so damaged that their content is nearly irretrievable, yet if we leave enough in enough locations, at least some may survive intact.

Another option is to protect them with coatings or cases that prevent various types of damage. There are no transparent coatings that are strong enough to not be destroyed or removed by someone making a concerted effort, or someone who is extremely stupid or accident prone. Instead of attempting that, a better solution is to use protective enclosures.

For example, we might try to enclose Arch Discs in solid metals or solid rock -- such that they cannot be detected, or retrieved, until the recipients have achieved a sufficient level of technology to be able to handle the artifacts without damaging them.

Another related approach is to place Arch Libraries in locations that are so hard to access, that only a sufficiently advanced civilization could locate and retrieve them. This is the approach being considered by our Civilization Boxes initiative.

Similarly we can place Arch Libraries in non-terrestrial locations around or near Earth and the Moon, such that they relatively easy to see with the naked-eye or with a telescope. In the case of naked-eye discoverability we might imagine using highly reflective materials in space, such as a large mylar surface unfolded from a satellite placed in a long-term orbit or the L4 or L5 points, such that it can be seen glittering or flashing in the sunlight against the night sky. Another option is a reflective beacon orbiting the Moon, however there are no stable orbits around the Moon, which would time-limit this concept.

There is another approach as well -- miniaturization. For example, we can make Arch Libraries so small they cannot be found or damaged until recipients are sufficiently advanced to not ruin them. One way we are are starting to explore this is through research into Molecular Storage in DNA.

In this case, an option is to encode future Arch Libraries into synthetic DNA molecules and then to embed these into substances such as Artificial Amber for long-term preservation and discovery in the future. Within 12 months of the writing of this article we will be able to encode the entire present Lunar Library dataset into a small tube of synthetic DNA as liquid or powder. DNA is quite stable if adequately protected.

Another option is to encode Arch Libraries into the actual DNA of living organisms, in a manner such that the encoded information is passed down through their biological lineages into the distant future.

One possible target for this type of synthetic biology approach that we have considered is to utilize the so-called "junk DNA" region of the human genome, or of other species, as the carrier region for a payload of genetically encoded knowledge. However, unless such information is somehow linked to a gene that has selective advantages to survival (such as reproduction, for instance), it would get weeded out by natural selection over time.

Our understanding of how the genome works, and what the non-coding "junk" sections do is not yet advanced enough to determine the safety and feasibility of this idea. It is very possible that modifying anything near or connected with any portion of a genome that has a selective advantage for an organism could also interfere with or damage an important function of the organism, causing the self-destruction of the message, and the genome that carries it, and the organism itself.[12]

It is worth exploring these questions carefully, safely, and scientifically perhaps starting with generations of safely time-limited bacteria in a laboratory setting.

On the other end of the spectrum, instead of miniaturization, we are also considering the option of protecting Arch Libraries by making them so huge they can't easily be accessed by non-qualified parties, or at least can't easily be destroyed. For example, by encasing them within or beneath very large and heavy blocks of stone or metal, or by encoding them into the construction of large physical monuments such as pyramids or monoliths.

Gigantic stone or metal monoliths certainly won't be destroyed by primitive peoples, and even today we would have a hard time destroying objects such as the pyramids. Gigantic Arch Library containers are just as interesting and valid as tiny ones, for long-term preservation and transmission of Arch Libraries on Earth, and probably are similar in cost to really achieve.

However, while making gigantic Arch Libraries is tempting, as it was for Shelley's *Ozymandias*, there are more people working on miniaturization today because of the growth the biotech industry, so that's probably an easier place to start.

There are also many other scenarios we have considered - such as designing for pre-industrial, industrial-age, information-age, and space-age recipients on Earth in the distant future. Those audiences are all explicitly within the scope of our design thinking and would be easily technologically capable of utilizing the Arch Libraries, assuming they recognize them as interesting and take the time to look more closely into their content.

Will Anyone Find It?

Only time will tell if The Billion Year Archive, or parts of it, such as the Lunar Library, will ever be found. If a piece is recovered it might be thought to just be an artwork of aesthetic interest and might not be analyzed and re-instantiated into an actively accessible library at that time.

[12] Do not try this at home.

But at least we can say that as the number of replicated instances of the Billion Year Archive increases, and the number of locations in which they are instantiated around the solar system also increases, the probability increases that at least some replicants of the Library could eventually be recovered.

The Billion Year Archive has been carefully designed to have the potential to persist in our solar system for up to several billion years. That is ample time for several distinct epochs of life on Earth or other planets in our solar system to evolve, develop, become extinct, and then for life to evolve again. If this happens enough times, eventually it may have a chance to survive long enough to evolve higher levels of intelligence.

Because highly intelligent life does exist on Earth at least, it is not impossible that it will continue here, or that if it is wiped out for a period of time, that it could evolve here again. Even if most present-day higher intelligent lifeforms are wiped out by a comet or other extinction-level event -- even if life has to start from scratch -- there is ample time to evolve the equivalent of today's humans again.

The Billion Year Archive distribution strategy is modelled after distributed offsite disaster recovery and database replication strategies that are routinely used in the information technology field to protect and recover data in the case of catastrophic loss.

Our approach is "many copies, many places." We aim to pepper the solar system with enough Arch Libraries, that if there is ever anyone here in the far future, there is almost no way they won't find them eventually.

As an added benefit of this approach, we can also have some confidence that if anyone finds one or more pieces of the Archive, they will not be able to locate and recover them all.

This may be counterintuitive at first, but we do not want anyone to find all of our Arch Libraries, in order to protect against a future recipient from monopolizing, hoarding, destroying, or otherwise preventing others from discovering and accessing the knowledge as well.

To prevent this risk, we are placing Arch Libraries, not only in obvious and published locations, but also in many secret, hidden and extremely inaccessible locations[13] that even we plan to forget.

Assuming that intelligent life either continues to exist in our solar system, re-evolves here, or visits and/or settles in our solar system from somewhere else in the universe, instances of The Billion Year Archive should be in enough highly-obvious locations around each place they might look, to be discovered by them eventually.

[13] Inaccessible today, but not necessarily in the distant future when the landscape of various planets has changed, or in long orbits that decay slowly -- or that only return to our solar system periodically over long intervals.

Will Anyone Be Able To Read It?

If any Arch Libraries are ever recovered, the next challenges will be for whoever finds them to realize that they contain something valuable -- and after that to help them as much as possible to access the value they contain. The Arch Mission Foundation has taken pains to increase the odds of both of these things happening.

The top layers of the Arch Libraries have been encoded as analog images, etched into pure nickel. These images do not degrade and do not require advanced technology to detect or read-out the content.

No computers or software are required to access the first layers of knowledge. The surface of the artifacts have visible holographically diffractive shapes, page shaped areas, image shaped areas, and letters around them, that can be observed with the naked eye -- and the content they contain is easily retrieved using a primitive optical magnifier.

The first recorded evidence of a magnifying device is in a joke in Aristophanes' *The Clouds*, from 424 BC,[14] although there are also artifacts that may be even earlier magnifiers. The level of magnification required to read-out the top layers of data in the analog layers of the Lunar Library is not much more advanced than a simple lens.

Compound microscopes began to become available in the 1674, when Anton van Leeuwenhoek first discerned cells and bacteria at 270X magnification, and by the late 1600s microscopy had advanced enough to see the analog images we encode into the Arch Libraries.

Since it is not an obstacle for a pre-industrial civilization that is at least as advanced as humans were in the late 1600s, to discern and extract the content of the analog layers of the Lunar Library, it certainly should not be a problem for a spacefaring one to access the content.

But if they can optically retrieve the content in the analog layers of the Arch Libraries, the next question is how can they understand what it means?

As Arch Mission advisor, and devil's advocate, Stephen Wolfram writes, despite our best-efforts, there is a reasonable chance that future intelligent lifeforms who may find pieces of the Billion Year Archive will not recognize them as information-bearing objects that contain anything interesting, useful, or understandable. [15]

They may just consider these artifacts to be nothing more than pieces of junk, or "ceremonial objects," "primitive art," or even just a tasty treat.

[14] https://en.wikipedia.org/wiki/Magnifying_glass#cite_note-2
[15] Martin Kunze writes, "

Fortunately we don't need to design for nickel-hungry, cellular-automata based cephalopods and while it is statistically possible that something resembling an Arch Library could spontaneously appear due to a fluke of Brownian motion, or could be created accidentally by nanolithography-capable bacteria in another galaxy, that is highly unlikely to occur in our solar system.[16] So at least we can slightly constrain the problem from the scenarios that Wolfram considers as possible, to the set of scenarios where the beings who might encounter the Arch Libraries are reasonably similar to humans, cognitively and physically.

In response to Wolfram's points, Arch Mission advisor, Martin Kunze, writes:

> To me it is not a question of life-forms being intelligent or smart. It is a question of how advanced a life-form is. In addition any technically industrialised society needs to have a few particular characteristics to develop/evolve into such one: curiosity, communication, information recording (writing, drawing). Any future technical species is subject to these characteristics which drive the evolution of intelligence. Therefore it will understand the nature of an information carrier. As soon as this society performs space flight and is able to find - and recover - a moon lander, it will try to explore the object. (for curiosity!)[17]

I agree with Kunze, but this does raise certain challenges which I have given some thought to in the past. How do we make something that can be assured to arouse curiosity in a very long time period?

We need to devise ways to make Arch Libraries as discoverable as possible, which also means making then easy to distinguish from other "junk" that may be nearby, as well as from the natural environment, and potentially also from other very interesting things in proximity that simply do not contain Arch Libraries.

One way to do this is through the physical construction of the Arch Libraries and any containers, devices, or pieces of architecture that they are integrated with. However, this doesn't solve the challenge of dust.

Lunar dust settles at a rate of 0.04 inches per 1000 years. The dust is kicked up by natural events. In 1 million years, if dust accumulated in this manner, then it is possible that anything now on the surface would be covered in dust and might not be visible to the naked eye.[18] One

[16] Anything resembling an Arch Library is pretty obviously artificial and information-bearing. But we recognize that this argument is not enough to convince skeptics like Wolfram. And to be fair, Wolfram has a point: just because something is artificial or even intelligently designed does not mean anyone intelligent will find it interesting or intelligently designed, among all the other equally interesting (and computationally equivalent to intelligently designed) things they could potentially pay attention to, especially if they are computationally equivalent to Stephen Wolfram. Furthermore, it is unlikely that anything is in fact computationally equivalent to Stephen Wolfram, therefore the chances are higher than Wolfram suspects that intelligences other than Wolfram may be fascinated by the Arch Libraries if they encounter one on a future archeological expedition.

[17] Excerpt from an Email conversation between Nova Spivack and Martin Kunze, February 22, 2019

[18] A simple calculation would yield 1016 meters of dust accumulation per 1 million years. But it's not quite so simple because as dust accumulated, it gets kicked up again as well. There is new dust falling on the Moon from space, but not enough to make the moon 1000 meters wider in diameter in a million years. Instead, most of the dust accumulation is the same material convecting around.

solution is to use structures that cannot accumulate dust -- such as poles, signs, flags, and other primitive indicators.

Another solution is to design a device that would attract sufficient attention in a future ground penetrating radar survey or magnetic survey of the Lunar surface, in the event it was covered by dust. It would have to be quite a magnetic anomaly to do that.[19]

Assuming the dust problem can be overcome somehow, we have considered the construction of passive and active beacons. Passive beacons could be mirrored reflectors that simply reflect the Sun's light in interesting ways. They might even use lenses and other optical structures -- made only of quartz glass for the refractive lenses, and metals such as nickel for the refractive lenses, such that they are durable for ultra-long durations.

It might even be possible to design a device like this that could use heat from the Sun to cause expansion of metal parts that cause the reflected sunlight to change angle suddenly in order to cause a "glint" that might attract more attention.

Another type of passive beacon would simply be a surface that is designed to reflect back, various types of EM radiation in non-natural ways, if anything ever surveys the area where it is located. This could use diffractive methods, or it could use resonance, like passive RFID.

Active beacons are more powerful for the purposes of attracting attention, but designing ultra-durable active beacons is difficult. Electronic components don't last long on the Moon. We don't know how to design electronic components that can run even for decades, let alone thousands of years.

Can we design an active beacon system that (a) can run continuously or periodically for a million or a billion years, or (b) can be preserved for such a time-span and then be turned on and still work? It would be quite useful to the Arch Mission Foundation if anyone reading this can solve it; it would provide a good solution to attracting attention to Arch Libraries in the distant future.

If we cannot help future beings recognize the Arch Libraries are knowledge, then there is a chance that they could end up being overlooked, or perhaps viewed as just ancient "ceremonial objects" or useless monuments.

[19] interestingly, there is a large magnetic anomaly on the Lunar surface, under Mare Serenitatis, which is where the SpaceIL Beresheet Mission (carrying the first Lunar Library) is landing.

The Possibility of Human-Like Intelligence

This section written by Arch Mission advisor, Martin Kunze, Founder of [Memory of Mankind](#).

For “human like” intelligence to evolve, a planet needs to have solid land/continents. Under water it is impossible to use *simple* redox-reactions to gain energy or to melt pure metals from ore.

Carbon based lifeforms are the most likely, due to statistics. There are no other chemical combinations with comparable uncountable varieties as C-H-N-O-compounds, particularly organic compounds. Fluid water as a solvent allows by magnitudes faster metabolism compared to e.g. fluid methane.

By “human like” I mean an emerging intelligent species, comparable to early humans, using fire. The use of fire brings us to the next parameter: An oxygen containing atmosphere.

If there is no free oxygen - no simple redox reactions - such as fire - are possible. This implies an oxygen producing mechanism: splitting CO2 by organism. This "oxygen crisis" was a step into much more sufficient access to energy for the early microbes.

If evolution is a universal principle it works similarly on other planets which have a comparable composition of elements as the earth.

Anticipating water worlds and under water energy sources: tidal forces (create heat) and geothermal “black smokers.” The latter are caused by volcanic activity, which is a side effect of plate tectonics , which eventually leads to solid land.

When you think about the "mechanism" which leads to intelligent, technically industrialised societies, then some parameters become apparent: curiosity, communication, altruism, something like "hands,” and an understanding of the "principle of cause and effect.”

Let's imagine beings, who learned to use solid stones as a hammer (to crack nuts). It may happen that these stones from time to time break apart or split and become useless, but one day, one individual makes use of a split stone's sharp edge. This individual shifts the tool from one use to a new one.

This is what we call creativity, but eventually it is an "error" in the copy, similar to what is happening in the DNA.

This individual adds a new tool to the "tool-set" and if it works out to be useful, it will be copied and applied by the other members of the group. By understanding what made the stone split

("cause and effect") they try to repeat this. Stone splitting becomes a new skill to produce sharper tools.

Splitting flint leads to very sharp stone blades. At some time or another this creates sparks which could light fire on dry leaves.

The organisms need curiosity to observe this new phenomenon of sparks, and not flee the fire from fear. If other individuals witness this they need a kind of communication to express: “how did you do this?”

In addition the organisms need altruism to share the experience with others. This is done by evolution - those societies who can communicate and share will have the better odds of survival. Altruism exists because it offers a selective advantage to a species.

There are species on our planet which exist much longer than primates but have not evolved into intelligent societies. I think to explore the reasons why not tells a lot about why we turned into an intelligent one.

Octopoda are intelligent but they die before their offsprings get born... imagine the shift of intelligence if and when they ever evolve to pass on their knowledge! They might build structures from material they have access to under water, making corals to build houses.... But eventually they would have to conquer land to use better sources of energy (and in consequence metals and artificial material compounds such as ceramic)

Another possibility is birds. They have a tens of millions of years evolutionary lead on humans, and some are quite intelligent, but they lack certain features such as altruism (a crow NEVER shows to other crows how to make tools; usually they hide it from each other) also they lack the advantage of having two free limbs to use as "hands".

My favourite choice of the next intelligent species on earth are racoons. They are curious, understand the principle of cause and effect, can use their hands freely, can cooperate. As for racoon altruism though, that is less clear.

It is said that we are limited by our anthropocentric experience - we cannot imagine worlds and lifeforms which are completely different from ours.

No! I think it is in fact very anthropocentric to create worlds in our fantasy which are NOT subject to the laws of physics and chemistry (and probability) - (such as the creatures in "arrival" - total b.s. I think it is more likely that other intelligences are NOT aquacreatures in metal spacecrafts, and do NOT communicate by ephemeral writings in gas clouds!)

Referring to cave painting (because I don’t see this in Wolfram's paper): I view this phenomenon as graffiti. I am sure that people 30.000 years ago, who discovered how to make

hand-prints on walls, did this everywhere - for fun or joy. They covered any free rock-wall with these printings (or animal-depictions etc) . Only the ones in some caves were preserved due to calcareous sinter processes. I am sure that from our present graffitis only the ones in deep concrete sewer caverns will survive 500 years or more.

Due to the principle of cause and effect, and due to the parameter of "curiosity," anyone intelligent and evolving after humans will likely be interested in the past, whether they are our own offspring in 100 years, or some descendants from racoons in 1 million years.

I dare to think that even advanced AI will be interested in its past (again: due to the principle of cause and effect, which implies time, regardless of whether a cause preceded the effect by a millisecond or a millenium).

If we would find a time capsule from an intelligent dinosaur civilization (see: silurian hypothesis) we would be definitely interested, and would take quite an effort to decode the content, although the aren`t our direct predecessors at all.

Various animals use tools and skills to access food. In the long run, comparable to the evolution on the DNA level, these skills improve, and some prevail because they yield selective advantages (to the individual or the community).

I think these principles are universal. We started here on earth because the chemical preconditions (the concentration of elements) enabled a species with the right mindset to discover simple access to energy use (e.g. fire in an oxygen atmosphere).

I conclude that the emergence of intelligent life within the universe is subject to very tight parameters, given by the fundamental forces of nature, which manifest in the laws of physics, as a result of chemistry, and in further consequence as a result of biology.

Messages we leave today will likely be understood as intentional by curious intelligent lifeforms in the future. Depending on the intelligence level of future finders, they can also extract the meaning.

The Arch Mission Primer

In answer to Wolfram, we have also taken steps to improve the chances that someone finding an Arch Library will recognize that it is special and worth examining more closely.

The Lunar Library contains many visually interesting, computationally complex, symbolic linguistic features that should attract attention and intellectual curiosity of intelligent beings that are at least as smart as we are.

For example, we cover the surfaces of our artifacts with high-resolution diffractive holograms and other features that are indicative of organized intentional design and language.
Also within the top analog layers of each Arch Library devices is a “Primer” that is designed to teach what our languages and concepts actually mean - by pairing visual diagrams and images of things, with words and definitions.

The Arch Mission Primer was initially built from science books such as visual dictionaries, visual encyclopedias, illustrated textbooks and handbooks. To build it we backed up a large set of the best visual books in print, by encoding them in analog form into the Arch Primer Layers.[20]

After making this first instance of the Primer, we asked ourselves how it could be maintained in the future, if the world continues to grow and change, yet the publishers of visual dictionaries do not keep up. We realized that there is a need for an open visual dictionary and encyclopedia that is not copyrighted, and that is easy to maintain on a crowdsourced basis, so we are building one.

As well as making our Primer easy to read optically, without a computer and without needing to understand our languages, we have also designed it to accomodate the needs of more advanced recipients with data mining capabilities.

For data-miners of the future, with machine learning capabilities, we provide many different images, illustrations and diagrams of each concept, across different levels of magnification, languages, and explanatory approaches.

We also include many formal linguistics resources that follow after the visual knowledge, such as the full analog content of the Wearable Rosetta Disk from our partners at The Long Now Foundation.[21]

What Are The Near-Term Benefits?

When designing a system to transmit knowledge across billions of years of space and time, we cannot be certain it will be received, or that it will be understood. The benefits in the distant future could be immense -- our work could, for example, transmit the legacy of the billions of humans in human history, to the billions of whomever come after us in the future.

Billions and billions of people (or the equivalent) could be affected, whether or not they all are alive at the same to realize it. But these kinds of benefits are so far in the future, from today’s

[20] Unfortunately, due to baroque mazes of interwoven copyright restrictions on some of the material we included, which even the publishers themselves cannot untangle, despite wanting to help us, we are not able to share what the present edition of the Primer content actually looks like, for at least 50 years, when all present copyrights will expire. However this is not a very long time to wait on the time-scales we work on.
[21] We have also included much more comprehensive comparative linguistic datasets and other comparative reference materials, including many copies of the PanLex datasets in different encodings and data structures, in the deeper, digital layers of the Lunar Library.

time-period, that they are hard to understand -- and they may not occur at all -- and if they do, we won't know about it.

It would be somewhat disappointing, if after spending thousands of years to pepper the solar system with knowledge that could last for eons, there turned out to be nobody to discover it -- or if for some reason, whoever is there can't find it, can't access it, can't understand it, or doesn't care.

Fortunately the process of building and delivering The Arch Libraries is itself very fruitful and beneficial to those who participate in are alive today -- whether or not anyone finds them in the future.

Unlike the benefits in the extremely distant future, these nearer-term benefits are already transpiring and may turn out to be as or more important than the long-term benefits.

To start with, the process of attempting to create, maintain and replicate a long-term backup of humanity across the solar system is a grand cultural project -- not unlike building the Pyramids or the Gothic cathedrals, and like such projects, this can catalyze developments in virtually all areas of human endeavor.

Pyramids and Gothic cathedrals challenged their builders to invent new technologies capable of realizing the ambitions of their designers. They also integrated art and science, religion, history, politics, economics, and all other aspects of the societies that built them -- and they kept generations of builders, craftsmen, artists, and laborers employed. The Billion Year Archive is similar in scale and difficulty to these projects, and has the potential to have similar impact on society, if we seriously pursue building it over the long-term.

We are trying to do something that nobody has tried to do before -- to our knowledge. Building a solar-system scale archive that can last for billions of years is on the one-hand quite interesting, and on the other hand, very far from anything with commercial or practical value today.

Because this is uncharted intellectual and technological territory, the questions and answers we encounter along the way are novel and ripe for innovation. Sometimes it takes an impossible dream to stimulate the creativity and innovation of society to make the impossible real.

The archiving challenge alone is a huge challenge. It requires many new technologies that are only starting to be invented today. These technologies are already being catalyzed, invented, and accelerated through our relatively grassroots level of activity -- but many of these technologies have important practical and commercial uses today, and for our emerging multi-planetary species.

Take for example, the different breakthrough storage media that The Arch Mission Foundation is helping to drive forward and apply today -- such as Nanofiche, 5D Optical Storage, and Molecular Storage in DNA, and new technologies in R&D, which you can read about here.

Some of these, like Nanofiche, can solve real problems for governments and corporations in the present day. Others, such as 5D Optical Storage and Molecular Storage are essential to enabling our coming Exabyte-scale world to function.

Also of near-term benefit is the work we are doing with the early pioneers of the burgeoning “newspace” movement -- the new wave of space entrepreneurs and commercial space venture startups. In working with these organizations to send Arch Libraries to increasingly exotic locations around the solar system, we bring them into conversation with a broader spectrum of thinkers.

If nothing else, our work is seeing present-day conversations across disciplines that would not naturally happen, such as between rocket scientists and people in the arts and humanities fields, and these outside-the-box interactions have the potential to lead to some very novel ideas and innovations.

Interdisciplinary collaboration between scientists, artists, researchers, academics, writers, and philosophers is responsible for almost every major scientific, technological, and cultural breakthrough in human history.

So it is no small thing to work to make such collaboration happen in the space industry. Space is the next frontier of human evolution, and becoming a spacefaring, multiplanetary species is key to ensuring our survival as a species. But without interdisciplinary participation, human civilization won’t live long and prosper in the difficult environments of space and other planets.

In short, you can’t build a civilization in space or on other planets if all you send are scientists, engineers and spaceship pilots.

Civilization requires more than just the sciences and engineering parts of humanity -- it requires all parts of society and culture -- it requires medicine, architecture, politicians, laws, food, entertainment, leisure, art, music, and so much more.

As Stephen Hawking and many others have observed, if humanity does not soon climb out of the gravity well of our present ecological niche and colonize the solar system, it is likely that we or nature will wipe us out in 100 years -- or at least in slightly longer thousand year timescales that are, from a geological and evolutionary perspective, vanishingly short.

If we are serious about becoming a spacefaring civilization, we have to add more civilization to our spacefaring.

The paradox we face as a species is that unless we soon become “not of this Earth,” we will not long be of this Earth. So it is imperative that we do everything possible to orient human civilization to colonizing the solar system as soon as possible, and to drive the development of the technologies and economic incentives to make this happen.

To accomplish this we need to find ways to help more people on Earth participate in, and experience, the movement towards space now, even if they can't yet physically go there yet.

One of our hopes at the Arch Mission Foundation, is that if we receive sufficient financial support to do so, we can give every kid on Earth their own personal space in the Billion Year Archive that we are distributing around the solar system. The shift in outlook and perspective that this could bring about is profound.

Enabling a child (or anyone of any age) to look up at the Moon and know that they are there is life-transforming. If large numbers of people are able to place themselves virtually on the Moon, through the Lunar Library missions, not only will they begin to think of themselves as members of a spacefaring civilization -- and that's how you start to put more civilization into spacefaring.

Keeping an Interplanetary Civilization Together

In addition to the above benefits, the process of building the Billion Year Archive may yield technologies and datasets that accidentally or intentionally help to bring about -- or at least hold together -- a near-term multiplanetary civilization, within the next few hundred years.

One scenario in which this might occur is the case where humanity spreads to several non-terrestrial human colonies in locations around the solar system, such as on the Moon, Mars and space stations. If this happens, one of the challenges, and risks, that we will begin to face as a civilization is keeping the large volumes of information produced by each of the colonies synchronized across these distances in space and time.

The backbone of a civilization is its information commons, which may be embodied in a set of traditions and rituals, or in architecture and artworks, or in the form of written or electronic records and communications media.

It is this information commons that records, transmits and weaves together the basic fabric of civilization -- its traditions, laws, history, news, knowledge, economics, and social mores, beliefs and values.

If the information commons splinters, the result is an inevitable splintering of civilization. This is why it is so important today, even here on Earth, to make every attempt to keep the information commons of this planet as connected, open and accessible to all people and nations as possible.

In the case of an interplanetary civilization, this risk of unintentional, or intentional, splintering is even greater than on Earth.

The distances involved are the primary obstacle. For example, a one-way Internet ping between earth and Mars would take between 8 and up to 48 minutes, depending on where each planet is located in their orbits, and two-way interaction would be twice as slow. A conversation would be painful to say the least.

In addition to delay issues, there is the challenge of occlusion by the Sun, and various moons that might orbit into the path of transmissions. The bandwidth limitations in space today are also a major obstacle to transmitting anything close to "big data" between planets.

These issues pose many challenges to keeping future colonies around the solar system connected into a single cohesive civilization.

It has been extremely difficult, for thousands of years, just to make the people of planet Earth feel and act connected enough to function as one civilization right here on Earth. If we cannot even solve that, with all our advanced technology today, and all the years of history we have had so far, we will have a very hard time solving it between planets.

Until interplanetary communications technologies become dramatically more powerful, or the speed of light is overcome, the amount of data that colonies on different planets will need from each other, in order to feel and act as one civilization, will far outstrip our ability to deliver it in anything close to real-time.

If no solution to this is found then the colonies will start to have increasingly different information commons. Their data, mass media, economies, legal systems, cultures and societies will split apart and develop into separate civilizations -- at least until they can be re-connected together at higher bandwidths someday.

This is not necessary bad -- something civilizations breaking apart and recombining in a Darwinian process leads to better civilizations in the future. However, we probably don't want to start out with the assumption or intention of that happening.

There is another solution many of these problems. Instead of attempting to push firehoses of broadcast (or narrowcast) digital data on the thin and highly delayed bandwidth that exists between planets, we might be more effective in shuttling physical big data storage modules back and forth on a constant basis.

This can be done not only by carrying the data in spaceships, but even by relaying it around a network of physical waystations that act as routers of these physical objects. For example, one type of router would be a robotic system that could catch small payloads that are sent towards them from other locations, and then shoot them back out to other routers at the next stop along the way. This relay system could shuttle supplies, people, and data around the solar system without requiring each payload to carry any (or at least much) on-board fuel. It would work perfectly for shuttling Arch Libraries back and forth around the solar system.

It is also possible to use the solar system as the equivalent of a cold storage jukebox. In this model, Arch Libraries could remain in orbital locations around planets, like rings of data. New cartridges could be sent to these ring locations for storage -- into specific sectors corresponding to their database addresses. To retrieve them, robotic rovers in those rings could travel to the appropriate cartridge, load it into a reader, read the content, and then either physically send it somewhere else, or better yet, just transmit the desired data.

It may be science-fiction, but it is possible that, if there is enough data to store, we might run out of space on the surfaces of planets and start storing it in space. If we added processors too this could have other benefits. Space is cold, there is abundant solar power, and there is a lot of free real-estate. It could be a good place to build the gigantic server farms and data clouds of the future.

While this type of solution could keep very large volumes of data synchronized between planets, it wouldn't do it in real-time -- but given bandwidth constraints it could still send more data in less time than radio transmissions. However if we start to move physical shipments of critical big data between planets, we have to protect that data against the harsh environment of space.

This is where the new archival technologies being worked on for the Arch Mission Foundation's Billion Year Library may prove to be useful for nearer-term space data sharing.

These technologies are perhaps the only viable solutions *today* for safely shuttling critical physical data assets back and forth between planets -- and for ensuring long-term access to critical data on the surfaces of other planetary bodies like the Moon and Mars that have strong temperature changes and lack magnetospheres.

With future innovation and development of solar system communications infrastructure, the available bandwidth between planets could increase substantially, but the time delay and solar and planetary occlusion issues will never go away. So it is likely there will still be limitations on the communications between the colonies and outposts of a potential future solar system-scale civilization.

Shuttling data around on physical storage media has many risks. High-temperature, high-radiation environments are deadly to all known forms of digital and analog storage today -- except the technologies being researched and developed by The Arch Mission Foundation and its partners.

While insulation and EM shielding can provide levels of protection, the only way we can presently think of to guarantee that critical data is not lost, or at least that if it is lost that it can be locally recovered, is to use non-carbon based, radiation-proof storage media like Nanofiche or 5D Optical Storage.

Likewise, there is also another important scenario where The Arch Mission's perpetual archival solutions may prove useful: namely, the case where the communications links, and even

physical delivery links, between colonies on different planets are temporarily or permanently lost or shut down due to a disaster or war.

If such a worst-case scenario were to ever unfold, and if the link took a very long time to restore or was never restored, it might be important to have local backup access to the archives of the other planet’s data.

In order to maintain and be able to restore planetary archives locally, over long periods of time, without HVAC or artificially maintained archival environments, there is no viable alternative to the technologies being pioneered in The Billion Year Library.

Benefits Here on Earth

Incidentally, even without an interplanetary civilization arising, there are compelling reasons to backup planet Earth, or large parts of it, right here on Earth today. It unfortunately might be needed sooner than we expect.

In the case of a global nuclear war or an extinction-level event, that shuts the lights of civilization off for years, decades or even centuries, only non-carbon based archives like those we are creating will survive long enough to help regenerate advanced civilization if and when conditions improve.

There is another near-term benefit of the work that The Arch Mission Foundation is doing: economic benefit. The R&D that into new materials and storage media, and new technologies for collecting, organizing, and teaching knowledge, have many commercial applications.

Already two spinout ventures have formed -- NanArchival and Blocktag -- out of research originally conducted in the context of Arch Mission Foundation initiatives, and several outside ventures have also benefited from being connected through Arch Mission researchers to technologies they needed in the Arch Mission community.

We expect that this is just the beginning of the commercial benefits, and benefits to civilization, that the Arch Mission will yield.